Value of satellite-derived Earth Observation capabilities to the UK Government today and by 2020

Evidence from nine domestic civil use cases

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Executive Summary

Study aims

This study aims to provide evidence of the current and near-term potential value of satellite-derived Earth Observation (EO) capabilities to the UK government. The subsequent value to industry as a supplier of EO data and applications to UK government is also investigated.

This information is intended to provide evidence for the co-ordination of EO exploitation across government.

The opportunity

EO capabilities and their integration with other data sources have the potential to underpin many public-sector processes. The EO market also represents a significant opportunity for UK industry given its potential scale and growth. Demonstration of the value of EO to UK government could encourage greater uptake, helping to drive this growth and the economic and societal benefits that result. Through its potential role as a leading customer of EO data and applications, the **UK government could catalyse the UK EO sector for future growth in the global marketplace**, and thereby support **even greater benefits for the UK.**

Study scope

This study is confined to **nine domestic civil use cases**. These use cases are: **Agriculture, Atmosphere, Built Environment, Coastal, Forestry, Flooding, Maritime, Meteorology** and **Transport**.

The study **does <u>not</u> cover Defence, Security, Official Development Assistance**, other overseas operations by UK government, or any other areas beyond the defined scope of these nine use cases.

Summary value definition

The study estimates the annual economic value of **EO** across the nine specified domestic civil use cases in the UK today, and the potential value by 2020.

Value is presented in terms of what EO capabilities offer the UK government over alternative methods within the use cases. This value relates to **operational cost savings, exceptional cost avoidance, better policy decisions and regulation, and catalytic benefits (to wider government, economy, and society) for the identified EO use.**

The values associated with EO supporting better policy making and regulation, and enhancing operational productivity, are likely to be significant, but are not quantifiable. These are instead referred to qualitatively.

Study limitations

Estimated value in this study is **constrained by the availability of evidence** – sourced from literature (both privileged and publicly available) and consultations with more than 60 stakeholders. Nevertheless, some uses and value within the nine use cases may have been missed. For example, limitations to time and resources means that it has not been possible to investigate the full breadth of use across the devolved administrations or all local authorities.

As a result, while this study has aimed to present an accurate assessment, **the true use, value and potential of satellite-derived EO within the UK government may be much greater** than that presented in this report.

Key findings

- **Satellite-derived Earth Observation** (EO) concerns the gathering of information about the planet's physical, chemical and biological systems via satellite-based platforms (including an increasing array of commercial satellites, Copernicus, Landsat and weather satellites). This information provides inputs into wider geospatial solutions for users across the public domain.
- Satellite-derived EO is **potentially a huge market** but is, to date, still **relatively immature** – with data improving, infrastructure advancing, and applications evolving continuously. Nonetheless, the overall global satellite-based EO market is buoyant and growing. Market studies suggest the global industry is worth **$43.7 billion** in 2017, expected to reach **$66.1 billion** in 2020 (**CAGR of 14.8%**)[1].
- London Economics' analysis of the UK space industry suggests that UK EO industry income (including Meteorology) was worth **£325 million in 2014/15[2]**. Assuming the CAGR growth rate identified for Europe (11.5%), the **UK EO industry income would almost double to £625 million by 2020**. *(The estimate of EO industry in this report is not directly comparable with the estimate provided for the global market forecast).*
- **Total spend on EO by government is significant –** estimated at **£1.2bn between 2014 and 2020**, equivalent to **annual average spend of £175m**. More than half of this expenditure is on upstream spending on Copernicus and EUMETSAT (52%), with the remainder accounted for by the UK Space Agency (UKSA) spending, mainly on science and upstream, (46%), and other central government spending (2%)[3].
- From the nine use cases examined, the **predominant use of EO is in Meteorology** – accounting for more than 90% of the current derived value, mostly driven by the catalytic benefits to the wider economy and society. This value reflects both the maturity of EO use in the area and the value that accrues to a number of diverse areas that rely on meteorological EO data to inform mitigation efforts and timeliness of intervention. There are four other areas in which the government currently uses EO. These are: **Agriculture** (mainly in terms of rural payments); **Flooding**; **Maritime,** and **Forestry** to a less extent.
- Meteorology aside, this study reveals that **present government use in the other eight areas examined is limited, variable and fragmented, if at all**. Government users tend to make use of Sentinel data and process the data in-house whilst little commercial data and few commercial applications are currently procured for operational use. From the sample of industry consulted, government EO use was found to support an **estimated £10 million per year of commercial revenue** for data and application provision.
- At present, current use represents **almost £1 billion per year in value** to government and indirect beneficiaries. Exceptional cost avoidance accounts for more than half of this (59%), followed by catalytic benefits to wider society (22%), and operational cost savings (19%). This estimate **includes £64 million per year of direct value** to government in terms of operational efficiency and exceptional cost avoidance.
- **Ongoing developments** in EO data, application innovation and the emergence of other enabling technologies are **driving the potential for EO use and its associated value**. Specific

[1] Source details are provided in section 2.2.1 of the main report where these figures are presented.
[2] London Economics (2016). *The Size and Health of the UK Space Industry 2016.*
[3] Source details are provided in section 2.1 of the main report where these figures are presented.

advances in imagery **by 2020** are likely to include: higher spatial and temporal resolution, multi/hyper-spectral images, increasing data frequency, video imaging, enhanced SAR capabilities, and improvements in atmospheric, weather, and climate data. These developments will be mirrored by developments in complementary EO data sources (e.g. drones) and technologies that will improve the storage, processing, analysis and application of EO data (e.g. cloud-based computing, big data analytics, artificial intelligence, machine learning, robotics and automation).

- **UK innovation in EO-based applications is growing**, driven in part by the availability of free Sentinel data. These UK capabilities are being used to pioneer new EO applications on a commercial basis both domestically and abroad, and R&D grants are supporting developments on a project-by-project basis. The UK Space Agency's Space for Smarter Government Programme (SSGP) is dedicated to funding projects for UK government via a modest budget. EO applications are also being developed under other programmes and some are designed for foreign governments under programmes such as the UK Space Agency's International Partnerships Programme (IPP).
- The total value of satellite-derived Earth Observation for government applications across nine civil areas is forecast to reach **£1.2 billion per year** by 2020. In the context of significant pressure on public resources, higher demand, and increasing public scrutiny, **EO offers a value proposition that is not fully captured** in these estimates: a capability to support the detection of change over large areas, consistently, often more quickly and more cheaply than other methods.
- The **potential for EO use by 2020** represents a **trebling in direct value** (i.e. operational cost savings and exceptional cost avoidance) for UK government to **£200 million**. **Additional direct value** to be gained in 2020 includes: Agriculture (£18 million), Built Environment (£8 million), Coastal (£1 million), Forestry (£22 million), and Transport (£86 million).
- A number of **factors constrain the value of satellite-derived EO to the UK government**: the UK is well-mapped, has strong existing monitoring infrastructures, is frequently covered by cloud, and is broadly a law-abiding society. To offer value to government, EO solutions need to offer better value-for-money than existing systems that rely on costly existing infrastructure, while seamlessly continuing (potentially long running) data series.
- The **market is fragmented**: consulted stakeholders for this study broadly fall into three categories: government practitioners; researchers and academics; and industry. Consultations suggest that different groups could benefit from more coordination efforts to connect procurers of data and applications to providers. Other factors limiting the uptake of EO in government include: lack of expertise to understand the value and capability of EO – particularly for innovative applications and integration with other emerging technologies; funding pressures; challenges associated with accessing EO data, and the time and cost of processing it. Furthermore, until an EO solution is proven, it must run additional to existing systems, causing additional costs over the period.
- There is an appetite across government to explore **further use of EO applications** and an interest in having a **route to doing so**.
- Current initiatives indicate that the UK government is likely to be an **increasingly smarter and more efficient** procurer of EO data and solutions by 2020.
- UK Government use of **EO is conducted against a rapidly changing backdrop**. Future technological developments will change what is possible; the role of the Geospatial Commission will come into play, and various uncertainties due to Brexit will resolve. All of this means that these findings will need to be monitored and updated over time.

1 Introduction

Earth Observation (EO) concerns the gathering of information about the planet's physical, chemical and biological systems via remote sensing and 'in-situ' instruments on the ground. Remote sensing covers a number of aerial and satellite technologies that collect information at a distance. Satellite-based platforms[4] are widely used. Their distance from the earth means that satellites possess the following strengths, relative to aerial or manual methods of data collection:

- Repeated collection of data at the same area at regular frequency (temporal resolution);
- Collection of data over large areas (scale);
- Collection of data covering remote areas;
- Fast turnaround of data;
- Potential for automated processing;
- Consistency of repeat/revisit data (suitable for time series);
- Objectivity of data collection; and
- Re-use potential.

As a result, satellite-based platforms are suitable for monitoring the land, oceans and ice-caps of the planet, and its atmosphere, and to identify changes and patterns for a range of economic and environmental applications – sometimes more cost-effectively than other methods.

This capability has the potential to underpin a number of public-sector processes. However, information on the extent of use of satellite-derived EO in the UK public sector beyond the meteorological, science and defence domains, as well as the value this generates has been limited.

This study aims to address this gap across a number of use cases. It does so by using desk-based research, a programme of consultations with more than 60 experts including an industry workshop with 16 attendees to estimate the annual economic value of satellite-derived EO across nine civil areas of UK government: **Agriculture, Atmosphere, Built Environment, Coastal, Flooding, Forestry, Maritime, Meteorology,** and **Transport**. Defence and applications beyond the defined scope of these nine areas are not reflected in study estimates. To this end, this study is arranged as follows:

- **Chapter 2** details the motivation, context, scope and limitations of the study;
- **Chapter 3** identifies the use and value of satellite-derived EO to the UK government across nine use cases at two points: current (actual) and 2020 (potential) – for each use case;
- **Chapter 4** identifies the value to UK industry from servicing this UK government need for satellite-derived EO capabilities;
- **Chapter 5** identifies the barriers that are preventing the wider up-take of satellite-derived EO across UK government; and
- **Chapter 6** concludes on the use and value of satellite-derived EO across UK government, and suggests future work in this area.

Note: Satellite-derived EO is the focus of this study. All references to 'EO' and related terminology are used interchangeably and refer to satellite-derived EO exclusively, unless otherwise stated.

[4] Satellite-derived EO describes satellite platforms that carry remote-sensing instruments, most typically at either a fixed point above the Earth's equator (geostationary orbit, at an altitude of ~36,000km) or in a circular orbit (LEO, at an altitude of 150-2,000km).

2 About the study

2.1 Context

In the context of significant pressure on public resources, higher demand, and increasing public scrutiny, previous research[5] has suggested that **EO data, combined with other sources of geospatial data, have the potential to deliver transformational changes** in government policy and delivery outcomes. However, existing knowledge on the nature, extent, and value of EO use within the UK government is very limited.

EO **does already support a number of areas of UK public policy-making and services**[6]. For example, the scale and frequency of monitoring that EO enables means that it: supports the UK's environmental management obligations at local, national, and international level; improves services such as weather forecasting; and provides evidence for policy decisions at national and global levels.[7] More comprehensive evidence of current use in nine use cases is presented in Section 3.

Total spend on EO across the UK government has been estimated at £1.2bn between 2014 and 2020, equivalent to **annual average spend of £175m**. More than half of this expenditure is on upstream spending on Copernicus and EUMETSAT (52%), with the remainder accounted for by the UK Space Agency spending, mainly on science and upstream, via ESA (including ESA's EO Envelope Programme) and also national programmes (46%), and other central government spending (2%).[8]

The EO market represents a significant opportunity for UK industry given its potential scale and growth. The global market is expected to reach **$66.1 billion** in 2020, based on a CAGR of **14.8%**.[9] London Economics' own analysis of industrial activities also confirms that EO is a priority market that supports growth in a number of UK industries. It estimates that services using **satellite-EO data supported industries with a total turnover of £234.7bn** (2014 data) and **GVA of £89.2bn**[10].

The UK has the chance to capitalise on the significant global market opportunity, by building on national EO capabilities and renowned research base to **achieve a leading share of this growing market.** If it can be demonstrated that there is value in doing so, the UK government could help drive this growth and derive both economic and societal benefits at the same time. And this is the purpose of the study – to help identify where the near-term opportunities for government lie.

By embracing EO technology developments in more areas, and by becoming a leading customer of a range of EO data and applications (where beneficial to do so), the **UK government could catalyse the UK EO sector for future growth** in the global marketplace, and thereby enable **even greater benefits for the UK.**

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[5] McKinsey (2016). *Earth Observation Data.*
[6] McKinsey (2016). *Earth Observation Data.* UK GEOS (2017). *UK-GEOS Outline Business Case, March 2017.*
[7] Written evidence submitted by National Centre for Earth Observation (SAT0017). Available here: http://data.parliament.uk/WrittenEvidence/CommitteeEvidence.svc/EvidenceDocument/Science%20and%20Technology/Satellites%20and%20space/written/27871.html#_ftn3
[8] McKinsey (2016). *Earth Observation Data.* Total expenditure of £175m accounted for as follows: i) Copernicus, £55m; ii) UKSA, £80m; iii) EUMETSAT, £37m; iv) Other central government, £3m.
[9] Geospatial Media and Communications (2018). Geobuiz: Geospatial Industry Outlook & Readiness Index, 2017 edition. See more detailed reference in section 2.2.1 below.
[10] London Economics (2016). *The Size and Health of the UK Space Industry 2016.*

And this process has already begun. With the advancing capabilities and the general pressure for public sector efficiency, there has been **efforts to promote the development of EO capabilities in government.** This has been clearly demonstrated following the formation of a '*cross Government Earth Observation Working Group*' and publication of a number of strategy and policy documents, which all highlight the use of EO to improve public sector effectiveness[11].

The value of EO has been particularly recognised by the devolved administrations – both the Welsh Government and Scottish Government are investing in EO application across largely environmental functions. For example, the Welsh Government has formed an EO strategy and strategic evidence group and secured a three year multi-million-pound investment in a large-scale demonstration and knowledge transfer initiative called Living Wales. The Scottish Government, through its Digital Directorate, leads a remote sensing group and is using research funds to pilot and operationalise a number of EO applications. These initiatives were stimulated by coordination with the Department for Environment, Food and Rural Affairs (Defra) Earth Observation Centre of Excellence.

Following these commitments, EO has been a **leading theme within a number of downstream grant programmes** for UK industry. Among others, these include those funded by the UK Space Agency (UKSA) such as the UK participation in the ESA Business Applications programme (previously the Integrated Applications Promotion programme), the Space for Smarter Government Programme (SSGP), the International Partnerships Programme (IPP) and the UK participation in the ESA InCubed programme; there is also some funding for satellite applications from Innovate UK. Defra has also emerged as a leading champion of EO, using SSGP support to develop a *Roadmap for the Use of Earth Observation*[12] and launch an EO Centre of Excellence[13] to deliver the Roadmap. Other departments could potentially benefit by learning from these efforts.

More recently, EO has emerged as a potential strand for the UK government's **Industrial Strategy Challenge Fund (ISCF).** This fund aims to strengthen the UK's science and innovation base as part of the government's broader Industrial Strategy to boost the UK's productivity and earning power[14]. By addressing gaps in the UK's domestic EO capabilities, this funding mechanism could support the increased uptake of market-driven applications of EO. For this to happen, funding decisions need to be underpinned by evidence on the current and potential use of EO.

The objectives of this study – to highlight the annual value that EO has to offer the public sector – is a recognition of this context. This study, in turn, provides evidence for the proposed **UK Government Earth Observation Service concept (UK GEOS).** The UK GEOS concept is intended to co-ordinate the UK government's EO interests and act as a one-stop-shop for EO products and services. In this way, the UK GEOS concept could potentially maximise the value of EO for government.

2.2 Vision 2020: the future of EO

This study estimates the value of EO to government across nine civil use cases at two points in time: current and 2020. In order to provide an accurate forecast of the value that can be expected by

[11] Examples include: UK Space Agency (2012). *Strategy for Earth Observation from Space (2013-16)*; UK Space Agency (2012). *UK civil space strategy 2012 to 2016*; UK Space Agency (2015). *National Space Policy*; and UK Space Agency (2014). *National Space Security Policy*.

[12] Defra (2015). Earth Observation: roadmap for use in Defra (2015 to 2020).

[13] For details, please see: https://defradigital.blog.gov.uk/2016/05/09/defras-earth-observations-centre-of-excellence-driving-innovation-and-change/

[14] Please see: Please see: https://www.gov.uk/government/collections/industrial-strategy-challenge-fund-joint-research-and-innovation#satellites-and-space-technology

2020, it is important to consider changes that can be expected by 2020. This includes wider market growth, supply-side (industry), and demand-side (government) developments that will influence the adoption and value of EO by 2020 and beyond. These changes are discussed below.

2.2.1 Growth of global market

The global satellite-based EO market is buoyant and growing. A meta-analysis of multiple EO market studies estimates the industry to be worth **$43.7 billion in revenue in 2017**[15]. This is expected to reach **$66.1 billion in 2020**, based on a **CAGR of 14.8%** over this period.

N.B. These estimates relate to the total *revenue* of the satellite-based EO market, which differs to the focus of this study – the economic *value* of EO to public sector users – but it provides an indicator of the scale of the global opportunity for UK industry.

With an estimated turnover of **$28.3 billion**, the downstream market – which includes commercial imagery data and value-added services – represents the largest satellite-based EO segment with a **share of 65%** in 2017. The downstream segment is expected to reach **$42.3 billion in 2020**, based on a **CAGR of 14.4%**.

The upstream market – which includes satellite manufacturing, ground-based systems, launch services, and payload manufacturing – was worth **$15.4 billion 2017**, or **35%** of the overall satellite-based EO market. However, faster than average **CAGR of 15.3%** over this period will see the upstream segment reach **$23.6 billion by 2020**.

These growth rates reflect the global picture. However, faster growth is expected in emerging markets such as South America (13.5% CAGR 2013-2020), Asia-Pacific (18.5%), Middle East (23.8%) and Africa (18.9%), relative to the growth in mature markets such as North America (8.1%) and Europe (11.5%). This means that **Europe's share** of the global satellite-based EO market is expected to be **20.1% or $13.9 billion by 2020**.

For reference, London Economics' analysis of the UK space industry suggests that the UK EO space industry income (including Meteorology) totalled **£325 million in 2014/15**[16]. Assuming the same CAGR growth rate for Europe presented above (11.5%), the **UK EO industry would almost double to £625 million by 2020**. The estimate of EO industry in this report is not directly comparable with the estimate provided for the global market forecast due to the UK study's narrower definition of the EO market (e.g. categorising all defence and scientific activities separately).

2.2.2 Supply-side developments

The market for satellite-based EO for government between 2017 and 2020 will be shaped by four supply-side developments:

- **Satellite-derived EO data:** The development of existing satellite constellations and the launch of new commercial satellites will improve EO capabilities, and therefore the value of EO applications for end users. Specific advances in imagery by 2020 are likely to include:

[15] Based on Geospatial Media and Communications (2018). *Geobuiz: Geospatial Industry Outlook & Readiness Index*, 2017 edition. Note that estimates are adapted from European Space Agency, Euroconsult, Northern Sky Research, KBV Research and Geospatial Media Analysis. Geospatial Media and Communications defines EO market to include aerial/UAV mapping, which includes all hardware, software and services. Given the focus of this study (on satellite-based EO only), estimates of the aerial/UAV mapping segment have been excluded from the figures presented in this section.
[16] London Economics (2016). *The Size and Health of the UK Space Industry 2016.*

higher spatial and temporal resolution, multi/hyper-spectral images, video imaging, enhanced SAR capabilities, and improvements in atmospheric, weather, and climate data. Specific examples of satellite technology developments that can be expected by 2020 are summarised in Box 1 below.

- **Non-satellite-derived EO data:** Developments in satellite technologies are mirrored by developments in complementary EO data sources, such as *drones*. A combination of the wide area of satellite and the spatial resolution of drones can support richer analysis. This is an important trend, as end users of EO data are increasingly agnostic about the data sources they use to meet their specific user requirements[17].
- **Enabling technology trends:** Several technology trends will improve the storage, processing, and analysis of EO data. For example, *cloud-based computing* (and *quantum computing* in the long-run) will support the cost-effective storage of and fast access to the large EO data volumes that will be generated by 2020. *Big data analytics* and *Artificial Intelligence (AI)* will also enable pattern recognition from large volumes of data. This will be particularly helpful for applications that require change detection. Finally, *robotics, automation, and digitalisation technologies of Industry 4.0*[18] will mean that data and applications can be delivered more quickly and at lower cost. To take full advantage of these technologies, effective governance, organisation and support will be important.
- **New business models:** The growth in suppliers and the volume of EO data will reduce the cost of EO data. To maintain margins, some suppliers will offer more integrated data service solutions. The EO market in 2020 will therefore be increasingly segmented between analysis-ready data on the one hand, and data-related services on the other.

Box 1 Developments in EO satellite technologies

Copernicus: ESA has recently launched Sentinel-3B (April 2018) and is expected to follow-up with the launch of the first Sentinel-4 instrument in 2019. Together with Sentinel-5, these launches will improve the oceanic and atmospheric monitoring capabilities of Copernicus[19].

Other large satellites: Access to Landsat data may change by 2020. The US government is exploring the possibility of reintroducing charges for Landsat data[20]. By 2020, ESA, NASA and JAXA are expected to launch a number of EO satellites, including Aeolus, EarthCARE, GRACE-FO, and ASNARO2. Together, these satellites will enhance our measurement of weather, climate, and the environment[21]. However, it should be noted that operational services are sometimes hard to build and run on science mission data alone. Similarly, Airbus and DigitalGlobe will also have launched the first part of their Pleiades NEO VHR optical constellation and their WorldView-Legion constellation by 2020, respectively. Both of these next generation commercial constellations will enhance the spatial and temporal frequency of optical EO data.

Small satellites: In addition to these larger missions, there is a trend towards small EO satellites. This is driven by reduced launch costs, the miniaturisation of technology, improved on-board processing, standardisation and higher reliability[22]. This trend will raise the quality and quantity of EO data, and thereby lower the cost of commercial imagery. Notable providers of commercial small

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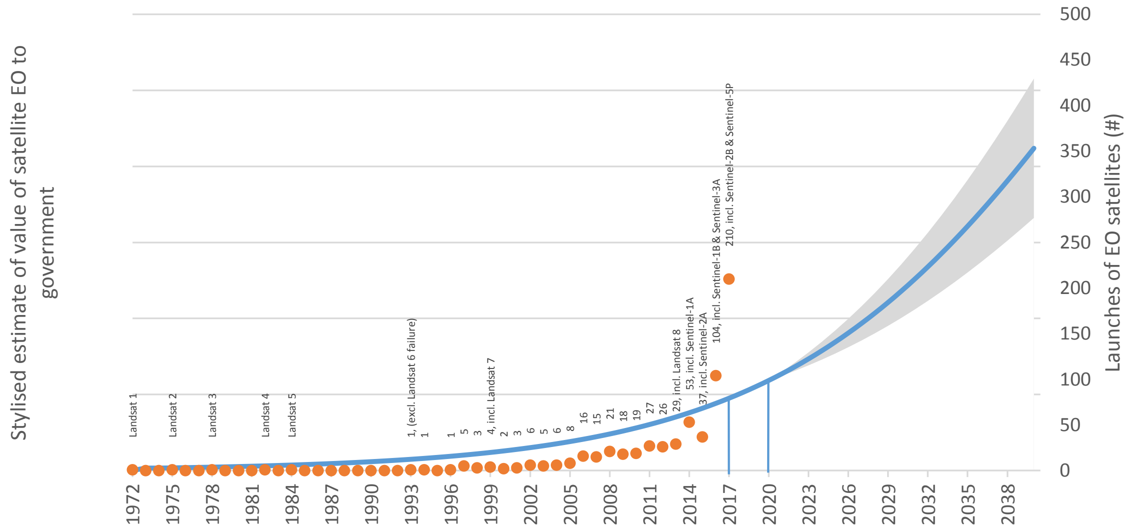
[17] Satellite Applications Catapult (2015). *EO21: Indicator of trends report.*
[18] Industry 4.0 is a name for the current trend of automation and data exchange in manufacturing technologies. For details, please see London Economics' forthcoming report: London Economics (2018). *Impact of Robotics, Automation and Digitalisation for space manufacturing.*
[19] For details, please see: https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4
[20] For details, please see: https://www.pixalytics.com/pay-for-landsat-data/
[21] Please see: https://www.pixalytics.com/4-eo-trends-2018/
[22] Satellite Applications Catapult (2015). *EO21: Indicator of trends report.*

satellite EO data include: Planet Labs, Spire Global, Spaceflight Industries, Satellogic, and Earth-i. These developments in small satellite technologies are also being utilised for intergovernmental science missions e.g. the joint UK-France MicroCarb mission for CO_2 monitoring, led by the UK Space Agency and the Centre National d'Études Spatiales (CNES).

The indicative relationship between satellite launches and the value of EO to government users is presented in Figure 1 below (notable historical launches of Landsat and Sentinel satellites indicated).

It shows forecasted strong growth in launches (more EO satellites were launched in 2017 than over the 2009-2015 period). The increase in data quality and quantity this implies suggests increased value to UK government in future.

Figure 1 Indicative relationship between number of EO satellite launches and the value of satellite EO to government



Source: London Economics analysis based on data obtained from: Union of Concerned Scientists (2017), UCS Satellite Database
Available from: https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database

2.2.3 Demand-side developments

The market for satellite-based EO for government between 2017 and 2020 will be shaped by four demand-side developments that will mean government is likely to be a smarter and more efficient procurer of EO data and solutions.

- **Understanding of value proposition:** Initiatives by Defra and the UKSA and the Geospatial Commission to showcase the value of EO through demonstration projects and stakeholder engagement are likely to improve departmental understanding of the value that EO can deliver. This will foster further uptake of EO in government.
- **Coordinated procurement:** The proposed UK Government Earth Observation Service concept (UK GEOS) could, if launched and operational by 2020 (as the reference point for this study), act as a single co-ordinating body for the procurement of EO data and applications in UK government. This could reduce the costs of procurement to industry and eliminate potential duplicate procurement of the same data on the government side. This could increase the uptake of EO data in government.
- **Government capacity:** At present, funding pressures make it difficult for officials to procure solutions from industry and to hire staff that can apply machine learning and other

advanced analytical techniques. As the value of EO becomes more widely understood, senior officials may be more likely to provide the funds to support investment in EO data and solutions. SSGP is helping to start this process by providing government officials with EO education opportunities and there is also a growing community of practitioners within government entities that are actively exploring the value of EO in different areas.

- **New infrastructure and methods:** The use of EO in certain areas of government is constrained by legacy infrastructure and methods. Once the value of EO becomes further established and proven, then government organisations will further open up to replacing legacy infrastructure and methods with new EO-based solutions.

2.3 Scope

This study set out with the objective of estimating the economic value of satellite-derived EO in nine important domestic civil use cases across the UK public sector. Given the time and resource constraints of this study, the scope of research and analysis is limited by the following:

- **Definition of value:** economic value has been defined to include the following:
  - **Operational cost savings:** productivity and efficiency gains that come from the use of EO to support operational processes over alternative solutions. These savings are quantified where possible.
  - **Exceptional cost avoidance:** additional costs that are avoided as a result of EO supporting government actions that would not be possible without EO. These savings are quantified where possible.
  - **Better policy decisions and regulation:** the value associated with better policy decisions and regulations that are enabled by EO data. These benefits are largely treated qualitatively.
  - **Risk mitigation** (**catalytic benefits**): the value associated with the wider benefits that accrue to third parties from the identified use of EO (i.e. to other areas of government and wider economy and society). These benefits are quantified where possible.

  To the extent possible, and as indicated, these sources of value are quantified in monetary terms. Estimates of value of EO in each of the nine use cases are quantified against these categories.
- **Scope of analysis**: civil government activities paid for by UK taxpayers. Wider uses, including defence applications, beyond these nine cases are not in scope.
- **Scope of government activity:** the use and value of EO is being identified across nine areas of UK government. These areas were prioritised following a preliminary research phase to identify areas of high current and/or potential use of EO. In order to direct research efforts, prioritise breadth over depth, and to eliminate duplication, the scope of these areas where tightly-defined as follows:
  - **Agriculture:** Rural payments; animal and plant health.
  - **Atmosphere:** Air quality monitoring; Greenhouse gas emissions monitoring.
  - **Built environment:** Planning; local services, biodiversity and conservation.
  - **Coastal:** Coastal erosion management; port planning.
  - **Flooding:** Flood planning; flood defence, and flood response.
  - **Forestry:** Domestic forestry resource monitoring and protection.
  - **Maritime:** Ocean monitoring; fisheries; and oil spill management.
  - **Meteorology:** Weather forecasting; climate policy.

    - **Transport:** Road; rail.

    In some cases, government policy areas are split across more than one of the nine areas in scope. **Climate policy** is one notable example, where government activities are split between Atmosphere (covering greenhouse gas emissions reporting) and Meteorology (covering climate research). Given the importance of EO for this area, the broader use of EO for climate policy is elaborated later.

- **Geographic scope:** The scope of the analysis is limited to domestic policy and operations of the public sector in the United Kingdom of Great Britain and Northern Ireland (with a few clearly marked exceptions).

The UK government runs a number of **grant-funded downstream R&D programmes** of relevance to this study and these support developments on a project-by-project basis. The most pertinent is the UK Space Agency's (UKSA) Space for Smarter Government Programme (SSGP) which is dedicated to supporting satellite applications and services for UK Government and the public sector. Other relevant programmes funded by UKSA include the Business Applications programme through ESA and the International Partnerships Programme (IPP). The UK participation in ESA's InCubed programme supports EO developments at a slightly earlier stage in the value chain. There is also grant funding from Innovate UK for innovative, commercially exploitable EO applications. Any benefits generated by these programmes are *not included* in the estimate of current value of EO to UK government. This is because these grants are designed to support pilot projects that test the feasibility of operational use and not operational processes that the government is obliged to deliver. Instead, only operationalised use of EO – where the government body spends its own budget on EO data acquisition, processing, applications, or end-to-end products – is considered in the estimate of current value.

When considering potential future value, however, the ambitions of the grant-funded projects are assumed to be realised, and the associated value is *included* in our estimates where possible.

2.4 Caveats and limitations

The research has been conducted by a team of independent professional economists with specialist knowledge of the space industry and Earth Observation, using best practice and best judgment to calculate the most robust and fair estimates. The methodology used, and assumptions made, are described in this report in a transparent manner, with caveats noted as required. Nonetheless, the reader should bear in mind the following high-level limitations and caveats of this study throughout:

- Satellite-derived Earth Observation is potentially a huge but, to date, still relatively **immature market**. As a result, it is difficult to forecast the evolution of application development and the future rate of adoption. We have attempted to estimate the economic impact of each identified use.
- **Characteristics of the UK** limit adoption of EO – the UK is well-mapped, has strong existing monitoring infrastructure, is frequently cloudy, and is broadly a law-abiding society.
- Focus on UK **domestic** policy and operations, rather than the large UK commercial and international markets for EO-derived applications (served by UK companies), is an important constraint on value.
- Scope limited to nine tightly defined civil use cases.
- This study only is focused on the use of EO for supporting operational processes – i.e. beyond that of a nonprofessional using Google Maps or similar services.

- This report portrays information based on privileged and publicly available literature and information gathered though interviews and engagements with more than 50 stakeholders. Nevertheless, government activities across the nine use cases are vast and varied, and – although unlikely – some individuals in government may use EO for specific applications within each use case, which has been missed.
- Information gathered from stakeholders is presented **at face value**, and assumed to be representative. This may add a **bias** to the findings. In some cases, the stakeholder may be unaware of or pessimistic towards the current and future potential of satellite-derived EO, whereas other stakeholders may have unrealistically positive views on potential.
- In Europe, benefits of EO are often estimated in aggregate and considering Copernicus satellites as well as in-situ sensors and other activities managed by the eight contributing European Agencies. **Isolating satellite's** contribution is a challenge, but is achieved on a case-by-case basis based published sources.
- To the extent possible (i.e. where evidence is available), the economic value of identified uses has been estimated in monetary terms. However, it is important to note that estimated value is constrained by the **availability of evidence**.
- Though we have endeavoured to present a true reflection of the current and future employment of satellite-derived EO capabilities by the UK government, the **true use, value and potential** of EO may be much greater than that presented in this report.
- The UK's impending exit from the EU (Brexit) presents two uncertainties in this analysis: i) potential changes to the UK's access to and capability to exploit Copernicus data, and ii) value that is derived from EO use in areas that are driven by compliance with EU legislation.
- At time of writing (**June 2018**), this report presents up-to-date findings. However, projects in various grant funded R&D programmes (including the SSGP, Innovate UK, ESA BAP, the EO Centre of Excellence, and IPP) may prove concepts that could alter the uptake of EO in UK government. These and developments in relation to the **Geospatial Commission** and **Brexit** means that these findings will need to be monitored and updated.

3 Value to UK government

The following chapter identifies the use and economic value of satellite-derived EO across nine areas of UK government: Agriculture, Atmosphere, Built Environment, Coastal, Flooding, Forestry, Maritime, Meteorology, and Transport. Economic value for each use cases is estimated at two points: current (actual) and 2020 (potential). The use cases are presented in alphabetical order.

The use cases follow a common structure, with a short introduction outlining the scope of the case study and the government's expenditure on activities in scope. The main findings for each use case are presented in a box that discusses the current use of satellite-derived EO (and estimated expenditure where possible) and associated value to government at present and by 2020.

3.1 Agriculture

The agriculture domain covers a large and varied group of government activities. For this study, the agriculture use case covers all government activities relating to **rural payments** and **animal and plant health**. Since this only represents a subset of all the government's activities in the agricultural domain, satellite-derived EO may generate more benefits in this domain than is quantified here.

Table 1 Agriculture functions

Function	Addressable by EO, current	Addressable by EO 2020	In scope for case study
Control checks for Basic Payments Scheme (BPS)	✓	✓	✓
Audit and quality assurance of RPA field data	✓	✓	✓
Proactive Land Change Detection (PLCD)	✓	✓	✓
Detection of bracken and scrub upland	✓	✓	✓
Crop Map of England (CroME) data set	✓	✓	✓
Plant health monitoring	×	×	✓[23]
Animal health monitoring	×	×	✓
Habitat monitoring	✓	✓	× (✓)[24]
Water management and drought monitoring			×
Environmental regulation			×
Agricultural supply and demand mapping			×
Freshwater fishery monitoring			×

In the UK, **rural payments** is a devolved responsibility. The Rural Payments Agency (RPA) – an executive agency of the Department for Environment, Food and Rural Affairs (Defra) – is responsible for rural payments in England. The other nations of the UK deliver rural payments through the Scottish Government's payments directorate, Rural Payments Wales, and the Department of Agriculture and Rural Development in Northern Ireland. Together, these agencies deliver subsidies under the EU's Common Agricultural Policy. In 2016, this amounted to a total of £3.4 billion in both

[23] Plant health monitoring for trees is includes in the Forestry use case (section 3.6). It has therefore been excluded from the agriculture case study to avoid double counting. All other types of plant health monitoring (e.g. of crops) are in scope for the agriculture use case.
[24] Habitat monitoring is included in the Built Environment use case (section 3.3). It has therefore been excluded from the agriculture case study to avoid double counting.

direct payments (£2.67 billion) and rural developments funds (£0.72 billion)[25]. To deliver these payments, the RPA spent a total of £132 million in 2016/17[26].

Animal and plant health is the responsibility of the Animal and Plant Health Agency (APHA). The APHA is an executive agency of the Department for Environment, Food & Rural Affairs, and also works on behalf of the devolved Scottish and Welsh governments. The APHA is responsible for: i) the UK's animal and plant disease investigation and response capability; ii) controlling the cross-border flow of animals, plants, and related products; iii) ensuring high standards of welfare in farmed animals, and iv) protecting endangered wildlife. Total expenditure on the APHA was £154.7 million in 2016/17[27].

Across these different entities, the UK government spends **£789.8 million** on agriculture activities[28], of which **£286.7m** are within the activities covered by this case study[29].

Box 2 Case study: Rural payments, and animal and plant health

Under the EU's Common Agricultural Policy (CAP) **Basic Payment Scheme (BPS)**, the rural payment agencies of member states are required to examine geographical features or land parcels as these are often conditions of BPS subsidy claims. The UK's Rural Payments Agency (RPA) uses satellite-derived EO to support this objective in a number of ways.

Firstly, rural payment agencies are required to inspect at least 5% of BPS applications each year in order to assess irregularities against claims. At present, the RPA conducts 75% of these inspections use satellite ('**Control with Remote Sensing**'). These sample checks require very detailed assessment, which is only possible using commercially available optical satellite data with a resolution of 1m or less[30]. The remaining 25% are carried out by manual inspections on the ground.

By supporting the rapid inspection of the majority of sample applications and directing the monitoring activities of the small team of physical inspectors at relatively low cost, satellite-enabled EO offers an operational efficiency relative to manual or aerial methods of inspection. Evidence from the RPA suggest this operational cost saving amounts to **£2.1 million per year[31]**. This is based on the need for an extra 60 FTE inspectors to conduct the 75% checks that are currently done via satellite. Similarly, evidence from Ireland suggests that the average cost of a physical inspection in 2010 was €1,800 compared to €60-70 for a remote sensing check[32]. In

[25] Estimates of UK receipts from the EU's Common Agricultural Policy (via the European Agricultural Guarantee Fund and the European Fund for Agriculture and Rural Development) are provided here in Euros: https://ec.europa.eu/agriculture/cap-funding/financial-reports_en The BPS payment exchange rate for 2016 has been used to convert estimates to GBP. These estimates are available here: https://www.gov.uk/government/news/bps-2017-payments-exchange-rate-set
[26] Rural Payments Agency (2017). *Annual Report and Accounts 2016/17.*
[27] Animal and Plant Health Agency (2017). *Annual Report and Accounts 2016/17*.
[28] Estimate derived from Defra's expenditure table, covering total resource and capital expenditure: Defra (2017). *Annual Report and Accounts 2016-17*. Note: agricultural activities have been refined to include the following Defra lines of expenditure: 'Food and farming', 'Animal and plant health', 'Countryside and rural services'.
[29] Relevant expenditure is the sum of total RPA and APHA expenditure in 2016/17.
[30] Please see: https://spaceforsmartergovernment.uk/case-study/remote-sensing-applications-consultants-and-airbus-ds-sentinel-1-in-support-of-cap-compliance-checks/
[31] RPA inspector FTE costs are assumed to be equal to the median gross salary of civil servants in the UK plus an uplift to account for pension and National Insurance contributions.
[32] Allen, M. (2015). Contextual overview of the use of Remote Sensing data within CAP eligibility inspection and control. Research Information Service Briefing Paper. Available here: http://www.niassembly.gov.uk/globalassets/documents/raise/publications/2015/dard/3115.pdf

addition, without the fast assessment of satellite, inspections would extend into the winter months where visibility (of crops and landscape) is poor. This would raise the chances of inaccurate and delayed inspections and therefore the likelihood of disallowance penalties from the European Commission.

Secondly, satellite-derived EO is used to support the **audit and quality assurance of the RPA's existing geographic dataset**. This process is required by the European Commission to assess the accuracy of payments. Significant inaccuracies with the quality and completeness of this data can expose the government to exceptional costs in the form of disallowance payments. Indeed, the National Audit Office identifies inaccuracies in the RPA's Rural Land Register as the *"most significant driver of disallowance"*. Defra's own estimates in 2015 suggest that efforts to improve mapping could reduce disallowance by **£213 million** between now and 2020[33] [34]. In the past year, this exceptional cost saving was worth **£43 million**.

Thirdly, payment agencies are required to operate a **Land Parcel Identification System (LPIS)** to uniquely identify all agricultural areas[35]. The LPIS underpins the BPS inspections process as it provides a record of a farmer's eligibility for payment. In response to the need to maintain and update the LPIS on a frequent basis to ensure that payments are based on up-to-date information, the RPA uses EO to support **Proactive Land Change Detection**. This process automates the detection of land change, thereby streamlining and directing the RPA's limited field inspection resources[36].

In addition, EO is used to support the **production of discreet data products**, such as **bracken and scrubland maps** and hedgerow datasets, and to produce the RPA's own crop classification map – the **Crop Map of England (CroME)**. The use of EO for crop classification removes the need for physical crop diversification inspections. This offers operational efficiency savings of approximately **£535-575K per year**, based on RPA estimates[37]. Wider use of CroME data across Defra can also support other policy objectives. For example, the Environment Agency can use crop map data to identify risk factors that may contribute to agricultural water pollution. If this data is used to support actions that could mitigate this pollution by just 1%, total catalytic benefits are estimated at **£12.3 million** per year.

Satellite-derived EO can be used to support the plant health monitoring in one of two ways. One technique involves **direct detection of plant stress** (an indicator of disease) using observations of plant colour and photosynthetic activity. The other technique involves **observations of risk indicators**, such as proximity to water sources and features that mitigate soil erosion.

The first of these techniques is currently at an early stage (i.e. R&D and not in current operational use). This is expected to change with the launch of ESA's Fluorescence Explorer (FLEX) satellite, which will provide global maps of vegetation fluorescence to indicate photosynthetic activity and plant health. This capability offers more direct plant stress identification than current experimental methods which rely on lower resolution data of biophysical parameters such as temperature and normalised difference vegetation index (NDVI) and would be significantly

[33] National Audit Office (2015). Managing disallowance risk. Report by the Comptroller and Auditor General, Session 2015-16.
[34] The difference between the 'do-nothing' scenario and 'investment' scenario is estimated at €260 million between 2017 and 2020. The EUR:GBP exchange rate of £1 equating to €1.15 as of 22nd April 2018 has been used.
[35] National Audit Office (2015). Managing disallowance risk. Report by the Comptroller and Auditor General, Session 2015-16.
[36] Please see: https://defradigital.blog.gov.uk/2017/04/07/why-defra-has-an-earth-observation-centre-of-excellence/
[37] Figures provided by Stott, Z. (2017). *Evaluation of Defra Earth Observation Data Integration Pilot – Strategic Overview.*

cheaper than visual surveying techniques (e.g. on ground or via aerial methods). This will support cropland and forestry monitoring, but only once FLEX has launched in 2022[38].

Data sources and methods do exist to support the second **risk feature identification technique.** However, there is a tension between the need for very high resolution (VHR) satellite imagery to detect farm-level detail (and thereby support more focused risk identification), wide area coverage, and the need for SAR to overcome cloud-cover issues. For these reasons, no operational use or value from EO is expected in the plant health domain by 2020.

The application of satellite-derived EO to support animal health objectives is also at an early stage. A combination of **risk feature identification**, **land change detection**, and **vegetation classification** techniques can be used to identify **environmental influences on disease outbreak** (such as identification of vectors). However, the application of these techniques to animal health face greater hurdles than in the plant health domain.

Similarly, the characteristics of most UK wildlife – i.e. small and mobile – means that direct monitoring of wildlife is beyond the capability of EO satellites by 2020. For this reason, there appears to be no scope for satellite-derived EO support animal health objectives either at present or by 2020.

Table 2 Benefits of satellite-derived EO for agriculture applications in scope

Function	Beneficiary	Current
Basic Payment Scheme (BPS) Control with Remote Sensing	Public/Private sector	£2.1 million
Audit and quality assurance of RPA's existing geographic dataset	Public/Private sector	£43.0 million
Crop Map of England (CroME) - RPA	Public/Private sector	£12.3 million

To conclude, the extent of use of EO within agriculture is very variable. On the one hand, EO supports a number rural payment processes, while on the other its application is only just being tested in the area of animal and plant health.

Since the use of EO in the rural payments domain is already very mature, EO is not expected to support new processes or products within this domain by 2020 that are not already using EO. This is reflected in the relatively stable estimates of 'value derived from EO' between now and 2020 presented below. This assumes continuity of CAP BPS payments, and the associated EO-based monitoring processes, in the UK during the Brexit transition period between 29th March 2019 and 31st December 2020. This is something, which the government has committed to into 2019 on the same terms as now (and assumed to do on equivalent cash terms until at least 2022)[39].

Even so, the extent of EO use within areas of existing use in rural payments processes could change. For example, the European Commission is likely to commit to a shift towards the monitoring of 100% of BPS payments from just 5% at present – a move that is enabled by the application of machine learning to EO data. However, the extent to which the UK adopts EO in this way or at all in the longer-term depends on the nature of the UK's agricultural subsidy scheme post-Brexit (where an

[38] Pease see: https://directory.eoportal.org/web/eoportal/satellite-missions/f/flex

[39] Downing, E., Sarah, C. (2018). Brexit: *Future UK agriculture policy. Briefing paper*, Number 8218, 21 January 2018.

EO component could be designed in from the start) and on the nature of the UK future relationship with the Copernicus programme.

The operational use of EO to support animal and plant health is unlikely to change by 2020, although R&D studies may have demonstrated the feasibility of EO use by then. Use is expected in the longer-term with the launch of ESA's FLEX satellite in 2022 and the more mature integration of commercial VHR data with free-to-access Sentinel data.

Despite this, the UK will face the same public services pressures as presently – i.e. the need to maintain service provision (and minimise environmental risk) in the face of pressure on Defra resources, higher demand, and increasing public scrutiny of the environment. In this context, EO has a clear value proposition – more specifically: the capability to do in-year monitoring of large areas of land very quickly and more cheaply than other aerial or physical methods of inspections. Sentinel data will likely have a role in supporting continuous risk monitoring (and providing information which the public can use to intervene to address environmental risks voluntarily), and higher specification EO products from the private sector could support more detailed observations of identified risks.

Table 3 Annual value of EO to UK government in the Agriculture Use Case

Function	Current, realised	2020, potential
Operational cost savings	£2.1 million	£2.1 million
Exceptional cost avoidance	£43.0 million	£61.0 million
Catalytic benefits (to wider government, economy, society)	-	£12.3 million
Total	**£45.1 million**	**£75.4 million**

3.2 Atmosphere

For the purpose of this study, the atmosphere use case comprises all government activities relating to **air quality monitoring** and **Greenhouse Gas (GHG) emissions monitoring**. The UK government's total atmosphere-related activities are broader than this – covering interventions to improve air quality and reduce GHG emissions as well as monitoring. For this reason, satellite-derived EO may generate more benefits in this domain than is quantified in this use case.

Table 4 Atmosphere functions

Function	Addressable by EO, current	Addressable by EO 2020	In scope for case study
Compliance with European Air Quality Directives	✗	✗	✓
Local authority compliance with Local Air Quality Management (LAQM) regime	✓	✓	✓
Air quality modelling and forecasting	✗	✓	✓
Providing evidence to support health impact assessments for specific air pollutants and mitigation strategies	✗	✓	✓
Validation and compilation of air quality component of National Atmospheric Emissions Inventory (NAEI)	✗	✗	✓
Validation and compilation of GHG component of National Atmospheric Emissions Inventory (NAEI)	✗	✓	✓[40]

[40] Climate policy is split between Atmosphere (covering greenhouse gas emissions reporting) and Meteorology (covering climate research). Given the importance of EO for this area, the broader use of EO for climate policy is elaborated in Box 10

Defra's research activities into causes and mitigation of air pollutants	×	✓	×
Supporting UN Reducing Emissions from Deforestation and Degradation programme (REDD+)	✓	✓	×

The need for air quality monitoring data is motivated by compliance with EU, UK, and UN legislation – i.e. the European air quality directives[41]; the UK Environment Act[42], and the UNECE Gothenburg Protocol[43].

In the UK, responsibility for **air quality monitoring** and meeting limit values is devolved to the national administrations in Scotland, Wales, and Northern Ireland. The Department for Environment, Food and Rural Affairs (Defra) has responsibility for the limit values in England and co-ordinates assessment and air quality plans for the UK as a whole[44]. The Environment Agency manages the UK's 284 national air quality monitoring sites on behalf of Defra and the Devolved Administrations[45].

The Department for Business, Energy & Industrial Strategy (BEIS) has responsibility for **Greenhouse Gas emissions monitoring**[46]. The need and requirements for a national inventory system (NIS) for reporting GHG emissions was established by the Marrakesh Accords of the Kyoto Protocol[47].

The UK government spent **£459 million** on **ambient air and climate** activities in 2015[48]. Approximately **£12 million**[49] of this annual expenditure is within the air quality monitoring and Greenhouse Gas emissions monitoring activities covered by this use case.

Box 3 Case study: Air quality monitoring and Greenhouse Gas emissions (GHG) monitoring

The UK's current air quality monitoring network is made up of a range of fixed monitoring equipment[50]. There are currently 284 national air quality monitoring sites across the UK, which monitor compliance against the **European Air Quality Directives**.

At present, satellite-derived EO does not currently offer a like-for-like substitute to the UK's existing monitoring network for **European air quality monitoring objectives**, and is not expected to do so by 2020, if at all. This is because there is no suitable European regulatory standard for the use of satellites, and satellites are not expected to offer the spatial and temporal resolution

[41] The European air quality directives: EU Ambient Air Quality Directive (2008) and the Fourth Daughter Directive (2004) set limits for pollutant concentrations in the ambient air.
[42] The UK's Environment Act places a requirement on the UK government and devolved administrations to produce a national air quality strategy. This sets out the UK's air quality objectives at national, regional, and local levels
[43] The UNECE Gothenburg Protocol sets national emission limits for SO_2, NO_x, NH_3 and volatile organic compounds which countries are required to meet from 2010 onwards
[44] Please see: https://uk-air.defra.gov.uk/air-pollution/uk-eu-policy-context
[45] Please see: https://uk-air.defra.gov.uk/library/annualreport/viewonline?year=2016_issue_2
[46] Please see: http://naei.beis.gov.uk/about/methodology
[47] Please see: http://naei.beis.gov.uk/about/national-inventory-system
[48] Latest figures based on ONS''s estimates for environmental protection expenditure by general government according to activity, for 1997 to 2015. Figures available here: https://www.ons.gov.uk/economy/environmentalaccounts/datasets/ukenvironmentalaccountsenvironmentalprotectionexpenditurebygeneralgovernmentunitedkingdom/current
[49] Estimate based on: i) total expenditure on NAEI; ii) FTE costs of Defra air quality monitoring team; iii) OPEX for air quality compliance network.
[50] Number accurate as of December 2016. These are operated by the Environment Agency on behalf of Defra. Please see: https://uk-air.defra.gov.uk/library/annualreport/viewonline?year=2016_issue_2

of the UK's current ground-based monitoring network by 2020[51]. For this reason, satellite-derived EO does not offer operational cost savings for the UK's European air quality monitoring objectives either today or by 2020.

These regulatory constraints do not exist for local authority level reporting which is required under the **Local Air Quality Management** (LAQM) system. For this reason, satellite-derived monitoring has been explored by some local authorities. For example, Leicester City Council and Rotherham Metropolitan Borough Council have partnered with the University of Leicester, via the UK Space Agency's Space for Smarter Government Programme (SSGP), and successfully demonstrated the feasibility of an "Air Quality Hotspot Mapper" which draws on Copernicus MACC II data. By integrating this data with other sources, this tool could provide local authorities with improved insight for decision making and mitigating the negative health consequences of poor air quality[52].

On the assumption that satellite-derived EO is used to support LAQM and therefore the adoption of more effective air quality interventions across all local authorities in the UK, the potential benefits of satellite-derived EO is estimated at **£4.1 million**[53]. This is based on the assumption that effective interventions reduce emergency hospital admissions for air quality-related emergencies (Chronic Obstructive Pulmonary Disease and asthma), and therefore the associated cost of these emergency admissions to the NHS.

Regulatory-driven monitoring activities aside, satellite-derived EO data has a significant role to play in augmenting air quality monitoring more broadly. This is because satellite data is sufficient (at 7km resolution column data – sufficient for some pollutants) to validate readings from the relatively sparse ground-based network. The expertise for this does not exist in government at present, but much of it is present in the science community (e.g. within the National Centre for Earth Observation) and is currently being applied to support the application of satellite data for air quality monitoring. This follows technical advances such as the launch of the TROPOMI instrument on Copernicus's Sentinel-5P satellite, which can provide more frequent and higher spatial resolution observations of ozone, methane and other atmospheric pollutants.

For similar reasons, satellite-derived EO data can also improve the **air quality modelling and forecasting** activities of government. For example, satellite data can: i) validate ground-based data inputs (triangulation of top-down with bottom-up), and ii) estimate the transboundary conditions (i.e. pollution movements across the UK border) of air quality models. By reducing uncertainty and improving forecast accuracy, satellite-derived EO data can support more effective pollution mitigation. This can reduce the negative health impacts of air pollution on UK citizens – estimated at £16 billion per year when considering particulate matter alone[54] – and the likelihood of infractions fines for non-compliance with European Directives[55]. Given the need to

[51] Ricardo Energy & Environment (2015). Investigating the Feasibility of Innovative Technologies to Improve Air Quality Monitoring over the Medium to Long Term. Available here: https://uk-air.defra.gov.uk/assets/documents/reports/cat20/1607061156_DEFRA_innovative_tech_Final.pdf

[52] Please see: https://spaceforsmartergovernment.uk/case-study/university-of-leicester-air-quality-hotspot-mapper-aqhsm/

[53] It is difficult to distinguish between the effect of improvements to LAQM and air quality modelling and forecasting on improved air quality interventions and their subsequent effect on air quality. For this reason, only one estimate has been provided for the value satellite-derived EO's contribution to both areas.

[54] Defra (2015). Valuing the impacts on air quality. Updates in valuing changes in emissions of Oxides of Nitrogen (NOX) and concentrations of Nitrogen Dioxide (NO2). Available here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/460401/air-quality-econanalysis-nitrogen-interim-guidance.pdf

[55] Following the UK's exit from the European Union, European Commission Directives will cease to apply to the UK after the transitional period – i.e. after 31st December 2020.

modify the air quality models to assimilate satellite-derived EO data – a process that is currently at trial stage – the benefits are not expected before 2020.

While not routinely used at present, satellite-derived EO will begin to play a role in the measurement of input data for the UK's database for supporting its international air quality and greenhouse gas (GHG) reporting requirements – the **National Atmospheric Emissions Inventory** (NAEI) by 2020. On the **GHG** side, satellite-derived EO is currently being trialled as a tool to assess **land use, land-use change and forestry (LULUCF)** drivers of GHG emissions. Here, satellite-derived EO is expected to support several input databases by 2020 (e.g. Ordnance Survey, Forestry Commission, soil, agriculture, natural habitat, transport and maritime movements). Similarly, the recently launched TROPOMI instrument will make it easier to identify the level of methane emissions over the UK. This data could be used to estimate the UK's Nationally Determined Contributions (NDCs) for the 5-yearly Global Stocktakes for the Paris Agreement on climate change. As a result, satellite-derived EO will result in cheaper, more frequent and potentially more accurate measurement of these databases. While much of this value is qualitative, consultations with experts suggests the cost saving could be in the order of **~£10,000s**, compared to the alternative of capturing land change data via aerial methods.

On the **air quality** side, satellite-derived EO is currently being trialled to measure the activity and associated emissions of specific sectors (transport, shipping, and livestock are notables areas of interest). Satellite-derived EO could reduce the uncertainty of measurement of these sectors, and therefore support more effective mitigation policies, although this is not expected before 2020.

Satellite-derived EO will offer significant value for a number of atmosphere applications by 2020. This is because satellite data can be used to augment ground-based data, improving some regulatory monitoring obligations (at a local and international level) and forecasting. This change is supported by the technical improvements offered by Sentinel-5P's TROPOMI, and the first of the geostationary Sentinel-4 instruments, which will launch in 2019. For example, satellite-derived EO is expected to continue supporting improved LAQM and air quality modelling and forecasting by 2020. By assuming that improvements in these functions support more effective air quality interventions and therefore a reduction in the number of emergency hospital admissions for air quality-related emergencies, satellite-derived EO is expected to offer **£4.3 million** in cost savings to the NHS.

The use of EO for **European air quality monitoring objectives** remains an exception – EO will not offer value in this area for both technical and regulatory reasons. On the technical side, satellite-derived EO does not currently offer the desired spatial resolution (i.e. 1km for rural areas and tens of metres for urban areas, depending on the particulate) at the required frequency (up to hourly) for many applications. On the regulatory side, European regulatory standards do not permit the use of satellite-derived EO for reporting purposes. For both these reasons, satellite-derived EO does not offer an operational alternative or cost-saving supplement to the UK's European air quality monitoring obligations either today or indeed by 2020.

Table 5 Annual value of EO to UK government in the Atmosphere Use Case

Function	Current, realised	2020, potential
Operational cost savings	-	Negligible
Exceptional cost avoidance	-	-
Catalytic benefits (to wider government, economy, society)	-	£4.3 million
Total	**-**	**£4.3 million**

3.3 Built environment

The built environment domain covers a large and varied group of government activities. For this study, the built environment use case covers all government activities relating to **urban planning, house building, local services**, **biodiversity and conservation**. Since this only represents a subset of all the government's activities in the built environment domain, satellite-derived EO may generate more benefits in this domain than is quantified here.

Table 6 Built environment functions

Function	Addressable by EO, current	Addressable by EO 2020	In scope for case study
Biodiversity and conservation	✗	✓	✓
Land Cover Mapping	✓	✓	✓
Housing	✗	✓	✓
Planning, regulation, and monitoring of buildings	✗	✓	✓
Construction	✗	✗	✓
Infrastructure planning and construction	✓	✓	✓
Local authority services	✓	✓	✓
Communications and Telecommunications			✗
Public asset management			✗
Energy mapping			✗
Waste and recycling			✗
Water and sanitation			✗

In the UK, **biodiversity and conservation** is delivered by a partnership of government, statutory bodies and non-governmental organisations.

The need for biodiversity and conservation is driven by a range of policies and legislation, including international agreements and European directives. More recently, the government's *'25 Year Environment Plan'* sets out a range of policies to support biodiversity and conservation in both the urban and rural environment. These policies include the introduction of wider natural capital benefits to planning decisions, proposals for a new environmental land management system, and a goal to mitigate and adapt to climate change[56]. The first of these provides a clear role for EO.

It should be noted that this plan is framed in the context of Brexit and the government's stated commitment to EU environmental rights and its obligations under existing international treaties beyond the transitional period (i.e. after 31st December 2020).

Responsibility for this function of government is devolved (to Defra in England, and the devolved administrations), while UK-wide and international aspects are the responsibility of Defra. Delivery of policy is discharged to a number of agencies, including Natural England, Scottish Natural Heritage, the Countryside Council for Wales, and the Northern Ireland Environment Agency, with UK-wide and international conservations functions are undertaken by the Joint Nature Conservation Committee (JNCC). Many other areas of government make important contributions, including those with

[56] For details, please see: http://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-8196

broader environmental remits, such as the Environment Agency, the Scottish Environmental Protection Agency, and the Forestry Commission[57].

In the UK, **local services** are delivered by **local government**. The structure of local government is fragmented, and the services they undertake vary[58]. One key function of local government is **planning**. Local authorities administer much of the planning system. As with local services in general, the responsibility for this function depends on the category of local authority. The Planning Inspectorate for England and Wales – an executive agency for MHCLG – undertakes responsibility for planning and enforcement on behalf of the Secretary of State. The UK's priorities for planning and housing are outlined in the government's draft *National Planning Policy Framework*. Total expenditure on local government amounted to **£2.49 billion** in 2016/17[59].

Box 4 Case study: Biodiversity and conservation, Land Cover Mapping, Housing, Planning, regulation, and monitoring of buildings, Construction, Infrastructure planning and construction, Local authority services

The UK government's *'25 Year Environment Plan'* outlines an ambition to improve UK's biodiversity and quality of living by placing the environment at the forefront of **urban planning decisions**. If this is to be done without raising the costs to developers, geospatial data has a role to support the monitoring and measurement of biodiversity indicators.

At present conservation agencies have tested a combination of satellite, airborne, and UAV solutions to compliment the **land mapping for habitat surveillance** that has been traditionally carried out by fieldwork. While this type of mapping is periodic in nature, the temporal resolution offered by satellites (and SAR in particular) can support the assessment of seasonal change and the inference of vegetation differences[60]. Remote sensing methods are also expected to underpin the **Essential Biodiversity Variables** (EBV) that are being developed to assess progress towards the 2020 targets of the Convention on Biological Diversity – part of the UK's international treaty commitments.

While the use of satellite for **habitat surveillance** and **EBV** monitoring is still in development and therefore not generating any quantifiable value at present, the UK has a number of existing satellite-based products that could support the time-series measurement of land cover and habitat extent.

At a national level, the **Land Cover Map** (LCM) is the land cover mapping component of the Countryside Survey – a 6-yearly exercise undertaken by the Centre for Ecology and Hydrology (CEH) to audit the UK's natural resources. Similarly, Wales has developed a more detailed map in partnership with the JNCC, which is also underpinned by satellite and aerial imagery. For more local assessments (e.g. of specific sites), the JNCC have been testing the measurement of biodiversity and natural capital through the creation of '**Living Maps**'[61].

[57] Medcalf K. A., Parker J.A., Turton, N., and Finch C. (2011). *Making Earth Observation Work for UK Biodiversity Conservation – Phase 1.* JNCC Report No. 495 Phase 1, JNCC Peterborough 2014

[58] Sandford, M. (2018). *Local government in England: structures.* House of Commons Library, Briefing paper, Number 07104, 6 April 2018.

[59] Please see: HM Treasury (2017). *Statistical bulletin: public spending statistics November 2017.*

[60] Please see: https://royalsociety.org/~/media/policy/projects/environmental-observation/environmental-observations-report.pdf

[61] Please see: https://spaceforsmartergovernment.uk/case-study/eo-dip-living-maps-for-biodiversity-and-natural-capital/

In each of these cases, satellite offers significant advantages over manual methods of mapping. Firstly, the cost of satellite data collection is only a fraction of field-based methods (between 12 and 25%, depending on the scale of measurement). Secondly, the scale of habitat and natural capital surveillance required on a national and frequent scale can only be feasibly done with satellite, as all other methods require resources that Defra cannot bring to bear on a frequent basis. In this way, satellite (particularly weather-resilient SAR) can be used as a **strategic tool** to: i) support early detection and therefore early intervention in the conservation domain, ii) assess the effectiveness of conservation interventions in a more holistic and integrated way, and iii) provide high-level change detection which identifies risks and can therefore direct more detailed mapping efforts more efficiently. If the Living Maps pilot were scaled to cover England's territorial area, total savings for a single update are estimated at £4.1 million, or **£7.7 million** if scaled to cover the entirety of the UK[62]. This is based on estimates of the cost of the Living Maps pilot relative to the existing non-satellite-derived EO method.

Local authorities represent another area where satellite-derived EO can play an increasing role. This is driven by the need for local authorities to deliver significant operational savings and improve income generation. However, the actual use of satellite-derived EO today is very limited. Most local authorities rely on aerial photography, since this data is available under the Public Sector Mapping Agreement (PSMA) and meets the high spatial resolution requirements of the monitoring work that local authorities require. In this context, satellite use is very experimental – i.e. the result of grant funding (e.g. SSGP) and/or of the enthusiasm of a small number of local authority champions. One notable example is the Milton Keynes **Urban Planning Service** demonstrator[63], which uses EO data to automate the monitoring of approved building work (i.e. building change detection and identification of illegal activity). This could offer operational saving relative to more resource-intensive methods of monitoring.

For example, early **detection of illegal planning** could provide local authorities with additional compensation revenues, and lower liabilities in the form of legal and "put right" costs. However, it has been suggested that satellite-derived EO would have to achieve spatial resolutions of 12.5cm for it to be a viable alternative to aerial photography (freely available under the PSMA) in urban areas[64]. However, spatial resolutions in the 50-70cm range, combined with the higher temporal frequency of satellite-based EO, may add supplementary value for some of these applications. Assuming this higher spatial resolution can be achieved, satellite could deliver potential net revenues from 'Breach of Condition Notice' fines of **£100,000**[65].

The value of satellite-derived EO will nevertheless be higher for local authorities that currently face difficulties with aerial mapping. For example, the wide swath, SAR and high temporal frequency of satellites (supporting image averaging), could offer large local authorities, and those subjected to frequent cloud cover, images that they would not be able to obtain through other methods of monitoring cost-effectively.

[62] London Economics analysis based on unit area costs provided by: Natural England (unknown). *Living maps: Satellite-based Habitat Classification*; Stott, Z. (2017). *Evaluation of Defra Earth Observation Data Integration Pilot – Strategic Pilot*.
[63] For details, please see: https://sa.catapult.org.uk/news-events-gallery/news/satellite-applications-catapult-and-milton-keynes-council-develop-pioneering-urban-planning-service/
[64] Spatial resolutions of 12.5cm are currently delivered by aerial photography. Several consultees stated that satellite would have to match this in order to be a viable alternative to aerial photography for planning enforcement applications.
[65] Net revenues are total additional revenues from the fines issued as a result of non-compliance with 'Breach of Condition Notices' minus the cost of administrative time to local authorities for issuing notices. All data sourced from: DCLG (2011). *Localism Bill: enforcement package. Impact Assessment.*

Other local authority areas where EO can play a role today include: identification of heat vulnerabilities in cities; supporting citizen access to public services, pollution monitoring, vegetation detection, and urban development.

However, budget constraints and the fragmented context of local government in the UK makes it very difficult for EO-based solutions developed in one local authority to be used by others on a commercial basis. For this reason, wider adoption of satellite-derived EO by local authorities may only be possible through the promotion of a national product. SSGP's '1:100' pilot project attempted to do just this – its aim was to create a single EO-based application that is geographically independent and could be used by a variety of government users for a number of different solutions. The sporadic and experimental nature of EO use in local authorities means that it has not been possible to attach a value to this use.

The use of satellite-derived EO for **house planning and building** is also limited at present. As with local authorities, this is because of the availability of aerial photography and other spatial data sources available under the PSMA. Assuming that spatial resolutions of 25cm can be achieved, satellite-derived EO can support cheaper and more frequent **monitoring of housing development**, relative to aerial photography and on-site monitoring. In addition, the historical times-series offered by satellite data could support: brownfield site identification; site acquisition (site hazards and access identification); rooftop development identification, and visualisation of the land registry. In these cases, satellites offer operational savings and broader reputational and social benefits for government. This is because these applications of EO could better support government reaching its house building targets. While these social and reputation benefits are hard to quantify, total operational savings from the potential use of EO for **validating housing output** is estimated at **£0.5 million**[66].

Satellite-derived EO has also been widely used to support **ground monitoring** for specific infrastructure projects, including the construction of **Critical National Infrastructure** (CNI). Examples of actual use include HS2 and the Jubilee Line extension, while areas of potential use include fracking and mining infrastructure projects.

The **Ordnance Survey (OS)** is another user that is testing satellite-derived EO to supplement its well-developed methods of aerial and ground-based sensor mapping. Satellite is not expected to replace these methods given OS's resolution requirements and the maturity of current surveying techniques. However, air space restrictions, the need for faster turn-around time on mapping products, and the advent of AI and automatic feature recognition methods, means that satellite-derived EO could play a role in wide-area hotspot detection and feature classification. In this way, satellite-derived EO could support faster change detection and direct the OS's normal aerial processes more efficiently.

The UK-GEOS Coastal Erosion and Accretion Project[67] delivered by OS demonstrates their on-going programme of activities to explore the suitability of satellite-derived observations to supplement high-resolution aerial data capture and reuse. This case study is explored in more detail in Box 5.

[66] Figure based in consultee and London Economics estimates of the total on-site inspections costs that are avoided as a result of EO use (i.e. travel costs and value of civil service staff time). Estimates of staff labour costs taken from: ONS (2017). *Civil Service statistics, UK: 2017.*

[67] Ordnance Survey (2018). UK GEOS Coastal Erosion and Accretion Project. Final Report, April 2018, Space for Smarter Government Project.

The use of satellite-derived EO is still being explored and tested – it is not expected to deliver realisable savings for UK-mapping products before 2020.

Table 7 Benefits of satellite-derived EO for built environment applications in scope

Function	Beneficiary	Current
Living maps	Public/Private sector	£7.7 million
Planning enforcement	Public/Private sector	£0.1 million
Housing output validation	Public/Private sector	£0.5 million

Across each of the areas in scope for this use case, satellite-derived EO is identified as a promising supplement to existing methods of mapping and monitoring.

The ambitions of the government's *'25 Year Environment Plan'* and the championing role played by Defra, means that biodiversity and conservation is an area where satellite-derived EO will deliver tangible value by 2020. In supporting the production of discrete data products, such as the Land Cover Map, this will represent an operational saving. In other areas, the value of satellite comes from its support of international treaty obligations (monitoring progress towards biodiversity targets) and input into policy making. In other areas, the value that satellite-derived EO can deliver by 2020 is much harder to quantify. In most cases this reflects both the experimental nature of use at present. However, the use of satellite-derived EO to support the construction of specific infrastructure projects and by Local Authorities and government housing bodies are notable areas of potential use by 2020. Indeed, SSGP has started work on a new infrastructure theme for R&D, focussing initially on nuclear.

These represent documented examples of potential use. However, there are a number of other areas that have been identified as offering potential for satellite-derived EO by 2020. These include the use of satellite data to support: mapping of the soil sealing layer in cities (i.e. the use of the Copernicus Urban Atlas to identify soil permeability), and the monitoring of building projects from monitoring through to construction. In this way, EO can provide visual intelligence that improve the allocation of resource-intensive inspections and support more cost-effective enforcement of building regulations.

Table 8 Annual value of EO to UK government in the Built Environment Use Case

Function	Current, realised	2020, potential
Operational cost savings	-	£8.3 million
Exceptional cost avoidance	-	-
Catalytic benefits (to wider government, economy, society)	-	-
Total	**-**	**£8.3 million**

3.4 Coastal

Coastal erosion management is closely linked to flooding both in terms of the physical processes at play and government activity. Water flowing inland from coastal floods causes particles from the soil and beaches to erode, which in turn weakens coastal defences. Hence, it is no surprise that the government bodies in charge of managing these hazards overlap. In addition to human activities, coastal erosion threatens habitats (e.g. saltmarshes)[68] which are subject to monitoring and mapping.

[68] JNCC (2016). *Threats to UK Coastal Habitats*. Available at: http://jncc.defra.gov.uk/page-5377 [Accessed 16 March 2017].

Table 9 Coastal functions

Function	Addressable by EO, current	Addressable by EO 2020	In scope for case study
Coastal erosion mapping	✓	✓	✓

Government expenditure on coastal erosion monitoring and flooding is often conflated; please see the separate Flooding section 3.5 for details on this. According to a report by Policy Research Corporation (2009), 10% and 15% of the total flooding and coastal protection budget of England and Wales (respectively) are dedicated to the coast, yielding a UK total expenditure of **£96.8m**[69].

Box 5 Case study: Coastal erosion mapping

The benefits of satellite-derived EO and remote sensing in general lie in their ability to inform coastal authorities about the optimal location of both manmade and natural coastal defences to defend assets and habitats threatened by erosion. In Scotland alone, between a quarter and half of all coastal buildings, roads, rail and water networks lie near the "soft" coastline – that which has a potential to erode[70]. £13.3bn of assets lie within 50m of the soft coast, so assets worth £340m are expected to erode by 2050.

Current use of satellite-derived EO is very limited. A rare example of use is in Morecambe bay where it is used to monitor sediment transport and elevation of the intertidal zone[71]. The ability of Earth Observation satellites to capture large areas at a high frequency is particularly suited for the large and highly mobile sand banks in Morecambe bay[72].

There are multiple data sources relevant to coastal. These include elevation data from a Digital Elevation Model (DEM) produced by the EA (available for England and Wales) through airborne LiDAR, which costs approximately £15m over a period of five years[73]. Further information sources include a variety of data from the National Network of Regional Coastal Monitoring such as air photography surveys, costing approximately £2m over periods of five years,[74] or ground-based surveys. The Scottish government spends approximately £350k on aerial photography, which is distributed to organisations for various uses. According to stakeholders, it is unlikely that satellite-derived EO would replace these for at least 5-10 years. Satellite imagery, however, could currently provide information on the distribution of coastal habitat at a coarser scale and could potentially aid the targeting of ground-based inspections.

[69] This is based on the total Central Government Expenditure on Flood and Coastal Erosion Risk Management, plus the EA local levy and other EA expenditure and funding of £381m between 2010/2011 and 2016/2017 by the Welsh Government on inland and coastal flood and erosion risk management (Auditor General for Wales, 2016). Auditor General for Wales (2016) Coastal Flood and Erosion Risk Management in Wales. Defra (2017). *Central Government Funding for Flood and Coastal Erosion Risk Management in England* and Policy Research Corporation (2009). *The economics of climate change adaptation in EU coastal areas*.
[70] Hansom, J.D., Fitton, J.M., and Rennie, A.F. (2017) *Dynamic Coast - National Coastal Change Assessment: National Overview*, CRW2014/2.
[71] Channel Coastal observatory (2015). *Programme Design*. Available at: https://www.channelcoast.org/programme_design/ [Accessed: 16 March 2018]
Mason, D., C., Scott, T. R., Dance, S. L. (2010) *Remote sensing of intertidal morphological change in Morecambe Bay, U.K., between 1991 and 2007*, Estuarine, Coastal and Shelf Science, 87 (2010), pp. 487-496. And Coastal Practice Network (2005) *The Planning, Implementation and Monitoring of Coastal Defences*, CoPraNet Seminar and Study Tour, 6-10 September 2005. North West England.
[72] Channel Coastal observatory (2015), *Programme Design*. Available at: https://www.channelcoast.org/programme_design/ [Accessed: 16 March 2018]
[73] Approximately 60% of this amount contributes to capture, and 40% to analysis.
[74] Here also, 60% of this amount contributes to capture, and 40% to analysis.

Although the coastline is already well-mapped through high-resolution airborne imagery, satellite-derived EO holds potential in updating maps of a rapidly changing coastline. This includes high-frequency change detection of *both* the mean high-water spring (high water mark) mean low water spring. Indeed, although the latter is commonly used to define the coastline, the intertidal zone, which lies between the two, is an important coastal defence. The frequent revisit rate offered by satellites can allow the reassessment of this after disruptive events such as a large storm.

The potential value of satellite-derived EO would derive from more timely awareness of coastal erosion, and a better understanding of longer-term coastal change patterns. The contribution of satellites stems from high-frequency updating, large area mapping and the fact that it is generally embedded in more automated processes than aerial photography (although the latter is unlikely to generate operational cost savings before 5-10 years)[75].

This could help government stakeholders (e.g. local authorities, the Environment Agency, the devolved administrations) to avoid inefficient expenditure – these *potential* **operational cost savings** are estimated at **£1m**.

A better understanding of coastal processes would also help stakeholders optimally place and maintain coastal defences (both natural and manmade), which could ultimately reduce the amount of coastal land lost to erosion. This could not only avoid the loss of valuable land but also that of valuable assets such as buildings roads, railway lines or airports[76]. These potential **catalytic benefits** are estimated at **£5.3m.**[77]Finally, as the main source of coastal change data is aerial photography and LiDAR-based Digital Elevation Models (DEMs), if air photography were replaced with satellite-derived EO, this could represent an operational cost saving of several hundreds of thousands of pounds: compared to £850k, the use of satellite-derived EO could cost approximately £35k. However, these benefits are unlikely to accrue before 5-10 years and are therefore not included.

Table 10 Benefits of satellite-derived EO for coastal applications in scope

Function	Beneficiary	Current
Coastal erosion mapping	Public/Private sector	Negligible

The developments between now and 2020 are expected to be limited, with a slightly greater role for EO anticipated.

Table 11 Annual value of EO to UK government in the Coastal Use Case

Function	Current	2020, potential

[75] This tendency may be explained by the emergence of software designed for application to satellite imagery. As an example, Correlated Land Change (CLC) was developed specifically for Landsat imagery. See also Stott, Z. (2017) *Evaluation of Defra Earth Observation Data Integration Pilot – Strategic Overview*.

[76] See Foresight (2004) *Future Flooding Executive Summary*. Office of Science and Technology, DTI London. See also Hansom et al. (2017) *Dynamic Coast - National Coastal Change Assessment: National Overview*, CRW2014/2.

[77] This assumes annual average coastal erosion of 1m/year over an eroding coastal length of 3,008km, with £340m worth of assets within 33m of the eroding coast and a property value of £1.33m/ha of coastal land – equal to the estimated residential value of one hectare in Suffolk Coastal. Moreover, satellite-derived EO is assumed to reduce land lost to coastal erosion by 1.25% (2.5% with 50% attribution to satellite data). DCLG (2015) *Land value estimates for policy appraisal*. Hansom, J.D., Fitton, J.M., and Rennie, A.F. (2017) *Dynamic Coast - National Coastal Change Assessment: National Overview*, CRW2014/2. Masselink and Russel (2008) *Coastal Erosion and Geomorphology*, in: Marine Climate Change Impacts Partnership (2008) MCCIP Annual Report Card 2007-2008 Scientific Review. PwC (2017), *Copernicus ex-ante societal impact assessment – Final Report*.

Operational cost savings	negligible	£1 million[78]
Exceptional cost avoidance	negligible	-
Catalytic benefits (to wider government, economy, society)	negligible	£5.9 million
Total	**negligible**	**£6.9 million**

Note: Catalytic benefits encompass savings from avoided coastal erosion and avoided loss of assets. These assets have not been separated between government assets (that would be classified as 'Exceptional cost avoidance'), and non-government assets (catalytic). As it is likely that the majority of coastal assets are non-governmental, so the benefits have all been presented as catalytic.

3.5 Flooding

Central government functions related to flooding cover the whole spectrum of activities such as forecasting rainfall, capacity for run-off (i.e. the elevation of the terrain, absorptive capacity of the ground and available capacity in rivers), and mitigating activities involving pumps, sandbags and other technologies. The main stakeholders in central government are the Cabinet Office (for co-ordination of emergency response), Defra, MHCLG, the Environment Agency (EA), the Met Office, the Flood Forecasting Centre (a working partnership between EA and the Met Office), devolved administrations, Lead Local Flood Authorities (LLFA), District and Borough Councils, water and sewerage companies, Internal Drainage Boards, and highways and rail authorities.[79]

Government functions relating to flooding can be divided into three activities. **Flood forecasting**, which is aimed at predicting the time and location of floods with enough lead time to allow authorities to issue alerts and take actions to mitigate the disaster. **Flood response**, the set of actions aimed at relieving affected populations and containing the flood when possible. **Flood planning**, measures taken over the long term to mitigate the impact of future floods, such as decisions on land use.

Satellite-derived EO data can provide inputs across the flooding process:

- **Hydrological models,** where soil moisture and river flows can be monitored;
- **Land-cover models**, where satellite data are used to model the permeability of the ground and in conjunction with hydrological models, its absorptive capacity for water;
- **Weather forecasts**, where satellites play a crucial role in the accuracy of forecasts (for more information, please see section 3.8); and
- **Flood response**, where satellite data through the Copernicus Emergency Management Services and the International Charter: Space and Major Disasters can provide a bird's eye view on the extent of the flood.

Table 12 Flooding functions

Function	Addressable by EO, current	Addressable by EO 2020	In scope for case study
Flood planning/prevention	✓	✓	✓
Flood forecasting	✓	✓	✓
Flood response	✓	✓	✓

[78] This assumes that Copernicus can help government save 2% of its expenditure on coastal erosion management, with an assumed 50% attribution to satellite data (as opposed to in-situ). This is based on an estimated £96.8m expenditure on coastal erosion management across the UK, assumption based on PwC (2017) *Copernicus ex-ante societal impact assessment – Final Report*.
[79] Local Government Association, *Managing flood risk: roles and responsibilities*. Available at: https://www.local.gov.uk/topics/severe-weather/flooding/local-flood-risk-management/managing-flood-risk-roles-and [accessed 18/1/2018]

Across the variety of government bodies responsible for flooding and the whole of the UK, the total expenditure on flooding amounts to **£796.3m per annum**.

Box 6 Case study: Flood planning/prevention, Flood forecasting, Flood response

Precise and accurate elevation data provides a crucial input into **flood planning and prevention** models along with hydro-meteorological data. The Digital Elevation Model (DEM) produced by the EA has a footprint in the order of 1 m and an accuracy of approximately ±10 cm. Currently, even the most precise and accurate satellite-based DEMs offer a footprint and resolution of an order of magnitude larger. For instance, Airbus's WorldDEM, based on radar data from TerraSAR-X and TanDEM-X SAR satellites has an accuracy of the order of ±1m. According to stakeholders, it is unlikely that satellite-derived EO will offer the footprint and accuracy required for the purpose of flood modelling before 5-10 years.

Elevation data is also an input into flood risk maps, most of which are produced by the Environment Agency, LLFAs,[80,81] and the private sector. These are based on a range of hydro-meteorological data, but also on land cover data, which provides information on impervious surfaces.

Satellite-derived EO can contribute to updating impervious surface maps, as has been the case in the United States, where satellite-derived EO has delivered **Operational cost savings** by allowing the automation of land use change maps. This is done through Correlated Land Change (CLC), which detects changes of land features from satellite images.[82] Annual efficiency savings from the use of Landsat images and CLC have been estimated at $4.5m, compared to the manual interpretation of aerial images. However, the properties of the UK (smaller landmass, existing infrastructure and processes) means that satellites need to improve significantly in performance to be able to replace existing methods and generate value.

Satellite-derived EO from the Met Office forecasts is a crucial input in **flood forecasting** models, which aim to predict the location and time of floods. The main variables that rely on satellite-derived EO data are potential evaporation (PE) and rainfall data. PE is a measure of potential moisture loss in the hydrological system. Without PE predictions from the Met Office, flood forecast models would revert to a seasonal profile of PE, relying on historical data. It could be argued that the availability of PE forecasts increases the performance of flood forecasting models by up to 5%. Rainfall predictions are by far the most important input to flood forecasting models.

Although it is difficult to determine the effect of satellite-derived EO on the performance of flood forecasting models, it could be argued that the forecast data provided by the Met Office allow the FFC to issue Flood Guidance Statements (FGS) at a county level with 2-5 days lead relative to 1-day lead at a UK level without such forecasts[83]. This increase in lead time offers flood response authorities and individual households critical time to procure sandbags and prepare for the event.

[80] The Environment Agency (n.d.) *'Flood Risk Regulations'*. The National Archives. Available at: http://webarchive.nationalarchives.gov.uk/20140328085714/http://www.environment-agency.gov.uk/research/planning/125459.aspx [Accessed 16 March 2018].

[81] The Environment Agency (2013) *Risks of Flooding from Surface Water – Understanding and Using the Map*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/297429/LIT_8986_eff63d.pdf [Accessed 16 March 2018].

[82] National Geospatial Advisory Committee (2014) *Landsat Advisory Group, 2014*

[83] Indeed, over the past 20-30 years, weather forecast lead times have increased from 2-3 days to 5 days for a given performance, largely due to satellite-derived EO.

There is also scope for improving information on soil moisture through satellite-derived EO. Currently however, the data does not provide enough information on how prone catchment soils are to flooding (in particular, satellites are unable to provide reliable information on deep soil) and is mainly useful for drought monitoring. It is unclear whether this information will be available from satellites by 2020.

Current catalytic benefits from flood forecasting are estimated at **£7.0m**. This reduction in damage costs was estimated at 1.5% in a value-for-money assessment of the Global Monitoring for Environment and Security (GMES) programme, the predecessor of Copernicus.[84] A more recent evaluation of the Copernicus programme has estimated benefits from reduced economic damages due to preparedness, prevention and mitigation, and those from improved responses at €97m and €24.7m respectively.[85] The corresponding benefits in terms of reduced fatalities and injuries are €1.8m and €0.9m. Note that these figures, however, were not calculated at the UK level and therefore partly reflect the vulnerabilities and scope for EO use in other countries (e.g. city centres in other countries may be less protected from floods than London, which makes the marginal benefits from EO use very high, given the scarcity of current flood defences). Reduced economic damages due to flood forecasting can be converted to the UK based on estimates of economic damages of floods in the UK vs. EU total.

Satellite-derived EO is used by the EA along with ground-based and airborne **flood response** mapping. While major decisions are not directly based on satellite-derived EO, this information provides flood response authorities with an overall picture of the disaster and can help gain awareness of areas that are not accessible from the ground. These satellite-derived flood maps can inform flood response authorities at a strategic level and enhance the accuracy of flood models in the future. It has also been argued that satellite-derived EO can increase the efficiency of decisions.[86] This can be interpreted either as a reduction in spending, holding flood damages constant, as a reduction in damages for a given level of expenditure on Flood and coastal erosion risk management (FCERM), or a combination of the two. McKinsey[87] has followed the latter approach and estimated the potential savings to the UK government based on an assumed 1% reduction in FCERM expenditure. PwC[88] has estimated the reduction in flood damages based on an assumed 0.5% reduction in flood damages thanks to the Copernicus Emergency Management Service (EMS). Flooding events in 2013 and 2014 led the UK to activate the International Charter: Space and Major Disasters to access an up-to-date view from above and assist in emergency planning.[89] The catalytic benefits from avoided losses due to improved flood response are estimated at **£7.4m** while the operational cost savings to government (England and Wales) from more efficient resource allocation is estimated at **£2.8m**.

Table 13 Benefits of satellite-derived EO for flooding applications in scope

Function	Beneficiary	Current
Flood planning/prevention	Public/Private sector	Negligible
Flood forecasting	Public/Private sector	£7.0 million

[84] Price Waterhouse Coopers, 2006, as cited in Booz & Co. (2011) *Cost-Benefit Analysis for GMES.*
[85] PwC (2017). *Copernicus ex-ante societal impact assessment – Final Report.*
[86] PwC (2017). *Copernicus ex-ante societal impact assessment – Final Report.*
[87] McKinsey (2016). *How can the government ensure more efficient and effective use of the increasing volume of EO datasets to improve policy outcomes, reduce costs and stimulate relevant industries?*
[88] PwC (2017). *Copernicus ex-ante societal impact assessment – Final Report.*
[89] Three activations in total across Yorkshire, Somerset, and Hampshire. For more details, please see: https://disasterscharter.org/web/guest/activations/charter-activations?country=united+kingdom&action%3Abrowse=Search

Flood response	Public/Private sector	£10.2 million

The future use of satellite-derived EO in flooding, considering the period to 2020 is considered likely to involve an increase in the uptake of the services. Assuming satellite-derived EO were to assist across all its likely domains, the increase in catalytic benefits is 50% between current and 2020, potential. This is primarily driven by the assertion that 78% of Europe's floods were mapped using Copernicus Emergency Mapping Service,[90] which has the potential to increase to 100%. Additionally, the effectiveness of the Copernicus services is assumed to increase over time.

Table 14 Annual value of EO to UK government in the Flooding Use Case

Function	Current	2020, potential
Operational cost savings	£2.8 million[91]	£2.8 million
Exceptional cost avoidance	-	-
Catalytic benefits (to wider government, economy, society)	£14.4 million	£21.5 million
Total	**£17.2 million**	**£24.3 million**

Note: Catalytic benefits encompass savings from avoided flooding and consequent avoided damages to assets. These assets have not been separated between government assets (that would be classified as 'Exceptional cost avoidance'), and non-government assets that are catalytic. It is considered likely that the majority of assets are non-governmental, so the benefits have all been presented as catalytic.

3.6 Forestry

The UK government has a stake in the management and monitoring of both domestic and overseas woodlands and forests. Domestically, the Forestry Commission assesses the size, composition and health of British woodlands and forests. Internationally, the UK government invests large sums in initiatives aiming to reduce deforestation and forest degradation (e.g. the REDD+ programme). Hence, it has a strong incentive to monitor progress towards these objectives. This case study, however, will focus on domestic applications of satellite-derived EO to the forestry sector, considering the National Forest Inventory and forest monitoring.

Table 15 Forestry functions

Function	Addressable by EO, current	Addressable by EO 2020	In scope for case study
National Forest Inventory	✓	✓	✓
Forest monitoring (e.g. timber supply, clear cutting, clear felling)	✓	✓	✓
Tree health	✗	✓	✓
Emissions reduction	✓	✓	✗
Supporting the monitoring of deforestation and forest degradation in the context of the UN-REDD programme	✓	✓	✗

In 2016-2017, the Forestry Commission's expenditure on public forests (England and Scotland) totalled £34.2m. Other expenditure by the Forestry Commission (England and Scotland) is £103.1m, including £61.6m on grants and partnership funding.

90 PwC (2017). *Copernicus ex-ante societal impact assessment – Final Report.*

9191 This assumes that EO can reduce expenditure on flood and coastal erosion management (FCERM) by 0.5%. This share is further discounted by 50% to account for the fact that McKinsey also considered non-satellite derived EO.

Box 7 Case study: National Forest Inventory, Forest monitoring (e.g. timber supply, clear cutting, clear felling), Tree health

The Forestry Commission GB (FCGB) is responsible for the monitoring of British forests and the publication of official statistics. The FCGB uses satellite-derived Earth Observation to identify and monitor land use change in forests and woodlands, clear cutting and clear felling as well as the planting of young trees.

The cost of conducting annual surveys based on satellite imagery amounts to £100k in total.[92] The use of satellite EO imagery allows both an **operational cost saving** and an **improved service** relative to the use of aerial photography, which used to underpin forest monitoring on a five-yearly basis, involving total costs of approximately £2m. Assuming that hypothetical yearly aerial surveying were to cost £400k, satellite imagery could be responsible for annual operational cost savings of **£0.3m**. Importantly, the use of satellite-derived EO offers substantially greater temporal resolution than aerial surveys, improving the efficiency of government activities.

Satellite-derived EO can also contribute to **exceptional cost avoidance** by helping to promptly identify fallen trees in the wake of storms, thereby allowing to recover most of their value rather than letting them rot: trees lose most of their value within six months of falling[93]. The use of satellite-derived EO to monitor wind damage also represents an operational cost saving compared to traditional field-based monitoring. If satellite imagery were able to detect individual trees, it would be possible to monitor endemic wind damage which often goes unnoticed.[94] This, however, would require a resolution of the order of 25 cm, which is unlikely to be adopted by the Forestry Commission by 2020.

Satellite-derived EO can also provide important **catalytic benefits**. The frequent updating of woodland and forest statistics can provide information to investors about the viability of the British timber processing sector, which contributes approximately £1.4bn per annum to UK GDP. Under the assumption that 5% of this value-added stems from investment that takes place due to assurance about the adequate supply of timber in UK forests, the annual value of EO – which provides the underlying information – is estimated to be **£2.8m**.

EO can deliver further catalytic benefits by informing resource allocation in plantations. Satellite EO data could provide further inputs into forest growth models, which currently heavily draw on assumptions due to the less-than-full coverage of existing data. These models contribute to planting decisions, which will affect the timber market several decades later. The information from satellite-derived EO could enhance these decisions and increase the competitiveness of the UK timber industry over the long term.

Satellite-derived EO can also help enforcement of waste disposal and deforestation **regulations** (e.g. monitoring compliance with logging licences). Currently, 100m tons of building waste are generated in the UK, some of which is illegally disposed of in UK forests. Satellite-derived EO could potentially reduce these incidents through frequent monitoring and the implied deterrence. It

[92] This includes the purchase of pre-processed Sentinel imagery made cloud-free (90%) by academia (£10k), analysis (£5k) and quality assurance etc. This process requires approximately 2-2.5 FTE.

[93] Janusz, S. and Wilkinson, S. (2017). *The Satellites That Safeguard Our Forests*. [online] Defra digital. Available from: https://defradigital.blog.gov.uk/2017/03/21/the-satellites-that-safeguard-our-forests/

[94] This is in contrast to damage from large storms, where larger areas are affected and therefore easier to identify, and the quantity of timber at risk is likely to trigger larger monitoring efforts.

has been estimated that, if EO could deter 50% of illegal waste generation in UK forests. This better enforcement of regulation could **avoid exceptional costs** of **£8.2m**.

Further **catalytic benefits** of Earth Observation may include the possibility of monitoring forest loss due to felling. Every year, 30,000-40,000ha of land worth £100-300k per hectare felled and 3-5% is not replaced. In addition to the loss to natural capital, this depletion of woodlands could also lead to a contraction in the downstream industries (e.g. timber processing). Currently, only 0.5-1% of sites of clear fell are currently monitored via ground inspection. Within the next five years, Synthetic Aperture Radar (SAR) data could potentially help identify young trees, and both replace ground surveys and enable the weekly monitoring of more clear-fell sites in order to ensure that young replanted trees survive – weekly monitoring would most likely not be feasible without the high revisit rate of satellites. Under the assumption that 100% of this loss could be prevented through the use of satellite-derived EO (and the further assumption that a solution is developed), the annual benefits could amount to **£28m**. The associated annual benefits from avoiding reduced activity at, and closure of, sawmills is estimated at **£7.1m.** In addition, the avoided loss of biomass would prevent an increase in net GHG emissions, preserve natural habitats, which are both of value to biodiversity and local communities.

There is also scope for using satellite multispectral imagery, SAR and thermal sensors to monitor tree health to support early intervention. Currently, accurate estimates from thermal sensors are hindered by noise (e.g. wind). Multispectral and SAR satellite imagery used in combination with adequate ground-truthing could provide updated information on disease outbreaks at a lower cost (currently, disease outbreak mapping often requires visual surveying – e.g. on the ground or from helicopters). Satellite-derived EO could also help target ground-based inspections and thereby contribute to the early containment of tree diseases. This could yield substantial benefits through the avoided loss of timber, habitats and carbon stores. The use of multispectral imagery for tree disease monitoring (for the most important species) is likely to be feasible before 2020 methodologically[95].

Multiple tree diseases have hit Europe in the last century, with the most prolific diseases all but eradicating whole species. For example, more than 80% of elm trees in the UK have died from Dutch Elm Disease since 1910. With the recent discovery of Chalara, or Ash Dieback, UK trees are vulnerable.[96] Considering only three particularly vulnerable species: ash, larch, and oak, the social and environmental value at risk is £339m, while the commercial value of the timber is £122m.[97] Assuming satellite-derived EO can identify the spread of the disease sooner, and thereby help secure even 2% of the woods in question, the **exceptional costs** that could be avoided are **£9.2m**.

Table 16 Benefits of satellite-derived EO for forestry applications in scope

Function	Beneficiary	Current
National Forest Inventory	Public/Private sector	£3.1 million
Forest monitoring (e.g. timber supply, clear cutting, clear felling)	Public/Private sector	Negligible
Tree health	Public/Private sector	Negligible

[95] As part of the Space for Smarter Government Programme (SSGP), Rezatec, along with Forest Research, have developed a tree species mapping and stress detection tool which could potentially fulfil this function for certain key species (SSGP, 2017). It is assumed that government funding will be made available to develop this product into an operational service by 2020.

[96] Forestry Commission (n.d.) *Top tree diseases.* (Online) available at: https://www.forestry.gov.uk/forestry/BEEH-9XLGXD [accessed 06/04/2018]

[97] Forestry Commission (2014) *Tree Health Management Plan*.

Overall, UK forestry sector also suffers from a lack of investment in monitoring capabilities, especially in comparison to Nordic countries. This is a major obstacle to unlocking value from satellite-derived EO, especially in cases where applications are technically and methodologically feasible.

Developments between now and 2020 are expected to include improvements in the applications identified in the box. The anticipated increase in the commercial satellites and associated improvement in spatial resolution is considered important for the realisation of benefits to forestry.

Table 17 Annual value of EO to UK government in the Forestry Use Case

Function	Current, realised	2020, potential
Operational cost savings	£0.3 million	£0.3 million
Exceptional cost avoidance	-	£22.4 million[98] [99]
Catalytic benefits (to wider government, economy, society)	£2.8 million	£38.0 million
Total	**£3.1 million**	**£60.7 million**

3.7 Maritime

The maritime domain encompasses a large and varied group of government activities. The 'Blue Economy' is a collective term capturing all activities related to the maritime domain, at sea, coastal, and the immediate hinterland. In the context of the present study, in-scope activities are considered in the present section as well as the 'Coastal' section 3.4. As not all Blue Economy activities are in scope for this study, satellite-derived EO may generate more benefits in the maritime domain than quantified here. Only government activities that use satellite-derived EO beyond a nonprofessional's use of Google Maps/Earth and meteorological outputs from the Met Office are considered.

Table 18 Government functions in maritime

Function	Addressable by EO, current	Addressable by EO 2020	In scope for case study
Aquaculture monitoring	✓	✓	✓
Fisheries monitoring	×	✓	✓
Oil spill monitoring	✓	✓	✓
Hydrography	✓	✓	✓
Ocean monitoring	×	✓	✓
Offshore energy	✓	✓	✓
Marine environmental monitoring	×	×	✓
Coastal monitoring and protection	×	✓	× 3.4)
Port and hinterland development	✓	✓	×
Search and rescue activities	×	×	×
Tourism	×	×	×

[98] The cost figures used are £350/tonne in clearance costs and £86.1/tonne in avoided landfill tax. It is also assumed that the total cost of fly tipping per area unit in the rest of the UK is the same as in England. Source: Defra (2017) *Fly-tipping incidents and actions reported by local authorities* 2012-13 to 2016-17. [Online] Available at: https://www.gov.uk/government/publications/fly-tipping-in-england [Accessed 5 April 2018]

[99] This assumes that by 2020, EO will be able to detect and deter 80% of illegal waste, based on incident detection rate of 80% in an Italian municipality based on very high-resolution WorldView 2 imagery, Drimaco (n.d.) A monitoring services to improve waste management at local level

Multiple government actors are active in the maritime domain, including Defra, EA, MMO, MCA, CEFAS, JNCC, MOD, UK HO and devolved administrations, agencies and trading funds. In addition, the European Maritime Safety Agency (EMSA) is a centralised European body that runs a satellite-based pollution response service for Europe. Across these different entities, the UK government spends **£395m** on maritime activities[100], of which **£105m** are within the activities covered by this case study.

Box 8 Case study: Ocean monitoring, fisheries, and oil spill management

Given the disparate nature of the government functions in scope, and the fact few government entities span multiple functions, each will be discussed in turn in this case study.

Ocean monitoring encompasses the monitoring of shipping vessels and the changing nature of the ocean and seabed. At present, shipping vessels are tracked using the Automatic Identification System (AIS), which is not in scope for this study of satellite-based EO.

Monitoring of **harmful algal blooms** (HABs) from space is the subject of a recently awarded grant-funded project[101] worth €3.7m and led by Plymouth Marine Laboratory. The project material asserts that the current cost of monitoring the English Channel for algae is €2m per year at 6% coverage. Using the satellite-based solution proposed in the project would cost €42,000 and cover the whole of the channel. The project description further suggests that damages of HABs to the fisheries and tourism industries in the area is €918m annually. The project is a scheduled for four years, so will not report its findings until after 2020. If the project proves successful, significant scope for savings to both UK and French authorities and industry exists.

The **charting of the seabed** is the responsibility of the UK Hydrographic Office (UK HO), a trading fund and executive agency under the MOD, which was set up in 1795. The responsibility for collecting data for the charting exercise is split between the Maritime and Coastguard Agency (MCA) (UK mainland) and the UK HO (British Overseas Territories and the Crown Dependencies). In addition, the UK HO gathers data and charts the waters around a wide range of Commonwealth countries through bilateral agreements.

Satellite-derived EO cannot be used to collect bathymetric data for the UK because the water is too dirty and the seabed therefore not visible. In other areas of UK HO responsibility, this is not the case. The UK HO trialled the use of satellite EO data in Antigua in 2014, and – following thorough verification of the findings – published a chart based on this data in 2016.

The UK HO is not formally obliged to continue its activities charting Commonwealth countries, but owing to the history of those countries and the experience of UK HO, it would be associated with severe inconvenience if the UK HO were to pull out. Many small-island developing nations are fully reliant on maritime shipping for everyday essentials, so the availability of an up-to-date and accurate nautical chart is a necessity. Using satellite EO to deliver at lower costs enables the UK HO to continue to deliver this service. This contributes to a positive perception of the UK.

[100] For EMSA expenditure, it is assumed that the UK's share of the EU budget (12.57% post-rebate) is a reasonable approximation of the UK's share of EMSA expenditure.

[101] Plymouth Marine Laboratory (2017), *EU project to monitor Harmful Algal Blooms from space*. Available at: http://www.pml.ac.uk/News_and_media/News/EU_project_to_monitor_Harmful_Algal_Blooms_from_sp [accessed 24/04/2018].

In terms of value to government, the hydrographic domain displays similar properties as many other parts of government. The findings using satellite-derived EO are thoroughly verified using ground-truthing, so there are no operational savings yet. In the future, it is easy to imagine that UK HO would use satellite techniques to increase the frequency of its outputs even if that would mean reducing the accuracy slightly.

Oil spill management is the responsibility of the MCA, which mobilises aircraft and vessels for inspection of reported oil spills. The European Maritime Safety Agency (EMSA) operates CleanSeaNet, a satellite-based early warning service to identify oil spills in Europe's waters, as well as a fleet of response vessels (one of which is stationed in Sunderland).

EMSA spends 13.3% of its budget on CleanSeaNet, yielding approximate UK share of the expenditure on the application of **£800k**. Over 2008-10, UK waters were imaged approximately 10 times per week, with an average of 0.33 detected oil spills per image. This enables the MCA to target its aircraft and verify whether an oil spill had occurred from an identifiable vessel.

In February 2012, the MCA was alerted by EMSA to a tanker that appeared to be trailing a slick of oily waste off Land's End in Cornwall. The captain claimed to have legally flushed its tanks, but satellite images used in court showed otherwise and the vessel's owner was fined for the action.[102] The economic benefits were only £22,500 in fines,[103] but at a more fundamental level, knowing that satellites are used to identify spillage could nudge captains to reduce impact of oil spills by adhering to the regulation that discharges are illegal less than 12 nautical miles from the coast.

EMSA sources data from Copernicus and the Canadian Radarsat constellation. EMSA estimate that the pooling of European resources saves 20%[104] on data access. Assuming this applies to total costs of EO through CleanSeaNet, yields operational costs savings for the UK of **£200k per year**. These savings are additional to the savings from using EO rather than aircraft. EMSA estimate the cost of EO at 10% of the cost of using aircraft. This yields a further UK operational saving of **£9m**.

The annual benefits attributed to Copernicus via EMSA in terms of reduced economic and environmental damages due to oil spills amount to €41.6m in 2017.[105] Attribution to individual countries by size of EEZ yields UK benefits of **£2.9m** in exceptional cost avoidance. As the number and severity of oil spills is decreasing, this value is estimated to decrease over time.

Environmental monitoring of the sea is a potentially significant application of satellite-derived EO. The current discourse focuses on ocean plastics, with development of domestic and international policies to combat the growing problem of plastic polluting the seas and oceans. Satellite-derived EO faces a scientific hurdle, as current instruments in space are unable to identify a spectral signature of plastic. In other words, satellite-derived EO can identify sheets of plastic optically but cannot be used to automate the identification of microplastics. ESA projects and start-up companies are currently exploring the possibilities of identifying plastics with EO satellites, but the timeline for any operational use is beyond the 2020-scope of this report. Even after cracking the scientific code to be able to identify microplastics in the ocean, the implications

[102] EMSA (2013). *Maersk Kiera. February* 2012. Available at: http://www.emsa.europa.eu/csn-menu/csn-service/oil-spill-detection-examples/item/1873-oil-spill-detection-examples-maersk-kiera-february-2012.html [accessed 13/03/18]

[103] The Falmouth Packet (9th October 2013). *Satellite Imagery busts tanker in Land's End pollution case*. Available at: http://www.falmouthpacket.co.uk/news/10726480.Satellite_imagery_busts_tanker_in_Land_s_End_pollution_case/ [accessed 13/03/18]

[104] EMSA (2011). *CleanSeaNet First Generation*

[105] PwC (2018). *Copernicus ex-ante societal impact assessment.*

are not clear. Reduction of plastics in the ocean is an international target, but it appears as if the most effective way of reducing plastic is to limit the inflow. It is known that 10 rivers in Asia contribute more than 90% of ocean plastic (which EO might be able to verify). Only after the flow of new plastics into the ocean is it efficient to start removing what is there already. To make any real progress here, technological solutions are required at scale.

Regarding **aquaculture**, the government's use of satellite-derived EO information is limited to a few specific areas. One such area is the Scottish Shelf Model (based on NASA TOPEX data) that is being used to model tidal flows and sea lice modelling. Similarly, modelling of Harmful Algal Blooms are of great interest to the aquaculture industry, as it enables evasive actions to be taken. The role of government in this respect is not as clear.

Satellite-derived EO information is not incorporated in governmental activities related to regulation and monitoring of **aquaculture**. Satellites are hampered by resolution and cloud cover, and consequently, current developments are moving towards drones or unmanned underwater vehicles rather than satellite. Potential usage could be imagined for the size of fish farms is consistent with planning applications, but further research is required to identify and fully reap the benefits of satellite-derived EO from the government's perspective. To remain sustainable, future fish farms must to be set up further from the shore than the current population. This complicates monitoring and regulation using the same means, so a role for satellite can be envisaged. However, this is not likely to occur at scale by 2020.

In the domain of **offshore energy**, satellite-derived EO can be used to locate wind turbines and monitor the sediment current around the turbines. This information is important from an environmental perspective as the placement of offshore wind turbines introduces a difference to the environment, which can result in new areas being subjected to sediment. This can all be modelled using meteorological information, but the EO satellites offer a means of ground trothing the models. Monitoring and regulation of wind turbines is limited, drawing instead on the self-reporting of developers. Satellite data are hampered by resolution (of free data) or price (of commercial data) and frequency of passes. In future, it is likely that the concentration of offshore turbines will increase to a degree that locating turbines by satellite is going to be the most efficient way.

Considering different types of **offshore energy** instead, the future potential from tidal modelling based on the Scottish Shelf Model (and similar solutions based on satellite) could be valuable for tidal energy. In general, the government does not verify claims and business models of developers (either in energy or aquaculture for that matter), but tidal energy zones could easily be defined with key inputs from satellite. This too, is not considered likely by 2020.

For **monitoring of fisheries**, the requirement is for near-real time, accurate data on location and identity of fishing vessels in the UK EEZ. AIS currently delivers sufficient data (as governed by international conventions and directives). Satellite EO is considered to have great potential for the combat of illegal fishing from dark vessels (with AIS switched off), but at present, the spatial and temporal resolutions mean that EO cannot be relied upon as a source. The UK Overseas Territories are more suited for the use of EO to identify dark vessels as the EEZ is less densely fished. The UK mainland EEZ, however, is so densely populated that identification of individual vessels and distinction of AIS transmission is complicated with current technology.

Satellite EO data cannot penetrate the water column and measure schools of fish, but it can be used in conjunction with AIS data to model fishing vessel behaviour as a proxy for the movement of fish. An on-going project at CEFAS studies the environmental envelope of mackerel, showing the fish are moving north in response to climate change. The Department of Exiting the EU use these findings to inform policy on future UK relationships with the EU in the domain of fisheries.

The value of these projects is difficult to quantify. Satellite EO offers information that was not previously available, which means that their costs are additional to the status quo. However, the value of informing the UK's future after leaving the EU could be substantial. The MMO reports[106] the value of mackerel catches by UK vessels in 2016 at **£189m**, so losing access to this stock because it is moving out of the UK EEZ would be costly. Assuming better information could help secure 2% of this catch would yield future savings of approximately **£3.8m**.[107]

Table 19 Value of satellite EO in maritime applications in scope

Function	Beneficiary	Current
Aquaculture	Public sector	-
Environmental monitoring	Public sector	-
Fisheries monitoring	Public sector	Negligible
Harmful algal blooms	Public sector	-
Hydrography	Public sector	-
Offshore energy	Public sector	-
Oil spill management	Public sector	£12.1m

A general finding across the functions considered in this case study is that satellite EO can be a valuable input into existing processes, but it cannot yet stand alone. Instead, it is necessary to verify the findings based on satellite with in-situ measurements.

EO is widely considered to have great potential, but in order to fulfil its potential, needs to improve spatial and temporal resolution. If this is realised, then EO information should be considered when existing infrastructure is up for replacement (e.g. AIS receiver stations).

The current use of satellite EO is hampered by technical limitations on the data. Using EO requires detailed verification before it can be operationalised.

Between now and 2020, on the other hand, many of those verifications could be completed, and in combination with the developments of video satellites and larger constellations with greater spatial and temporal resolution, could increase the use and value of satellite EO substantially.

Table 20 Annual value of EO to UK government in the Maritime Use Case

Function	Current, realised	2020, potential
Operational cost savings	£9.2 million	£9.2 million
Exceptional cost avoidance	£2.9 million	£2.6 million
Catalytic benefits (to wider government, economy, society)	-	£3.8 million
Total	**£12.1 million**	**£15.6 million**

[106] Marine Management Organisation (2017) *UK Sea Fisheries Statistics 2016*.

[107] Many British Overseas Territories and Crown Dependencies are reliant on fisheries as a key source of income, and therefore need to ensure they combat illegal fishing in their waters. Satellite EO can help by identifying areas where dark fishing vessels seem to operate. This information can then be shared with the local coastguards whose patrol vessels and aircraft can converge on known locations of illegal fishing. The patrol vessels must be mobilised and operated in all cases, but the use of EO can help improve the capture rate. This would be of importance to the territories, but the savings are not in scope for the present analysis.

3.8 Meteorology

The Met Office is the United Kingdom's National Weather Service and fulfils the UK government's meteorological functions. It operates as a Trading Fund[108], which in recent years has exceeded its Return on Capital targets set by HMT whilst providing free services to the general public[109]. It provides meteorological predictions across all timescales and supplies bespoke weather and climate services to private, commercial and government users in the UK and internationally. Moreover, the Met Office is a supplier of processed meteorological data, enabling the UK-based commercial market.

Table 21 Met Office functions in meteorology

Function	Addressable by EO, current	Addressable by EO 2020	In scope for case study
Climate research	✓	✓	✓[110]
Extreme weather and hazard warnings[111]	✓	✓	✓
Industry services (specialist forecasts)	✓	✓	✓
Provision of meteorological data	✓	✓	✓
Weather and seasonal forecasts	✓	✓	✓
Defence and security services	✓	✓	✗
International development and advisory services	✓	✓	✗

The Met Office receives no recurrent delegated expenditure limit (DEL) or annually managed expenditure (AME) budgets from HM Government, and gains all its revenue through contracts or contractual-style relationships with public and private bodies[112]. As a trading fund, its pricing for goods and services is established to deliver a return on capital to HM Treasury, delivered in the form of a dividend. In the 2016/17 financial year, the Met Office received **£194.8 million,** or **85.9% of its total revenue,** from public sector bodies. In addition, the Met Office funds part of its property, plant and equipment assets through capital grants from government[113]. In 2016/17, **government grant income of £11 million** was released to the Met Office, including part of the grant income for the supercomputer and polar satellite transfer from BEIS and a grant for the Department for Transport LIDAR project[114]. This is an unusual form of funding for the Met Office, as it mainly funds its capital requirement through apportioning depreciation charges onto its contract revenues[115].

108 A Trading Fund is a particular type of arms-length body established by a trading fund order under the Government Trading Funds Act 1973. The general criteria for establishment is where a majority of the revenue which the body will receive come in the form of revenue in respect of the goods or services delivered by the organisation, and where the responsible minister and HM Treasury are satisfied that the setting up of the trading fund will better enable value for money.
109 London Economics (2015). *Met Office - General Review. Economic Analysis.*
110 Climate policy is split between Atmosphere (covering greenhouse gas emissions reporting) and Meteorology (covering climate research). Given the importance of EO for this area, the broader use of EO for climate policy is elaborated in Box 10
111 The Met Office produces nation-wide warnings for both extreme weather evens (e.g. floods, windstorms, and snowstorms) and extreme temperature events (heatwaves, cold spells). Note that any benefits associated with the Met Office's flood modelling and warning systems have not been quantified in this case study, as those are considered in the separate use-case on Flooding.
112 London Economics (2015). *Met Office - General Review. Economic Analysis.*
113 Met Office (2017). *Annual report and accounts 2016/17.*
114 Met Office (2017). *Annual report and accounts 2016/17.*
115 London Economics (2015). *Met Office - General Review. Economic Analysis.*

Box 9 Case study: Met Office

The Met Office has used Earth Observation data operationally for over fifty years and considers satellites to be an integral part of its current forecast provision, directly impacting the quality of the forecasts they produce.

Over recent years, both operational meteorology and climate research conducted at the Met Office have grown increasingly dependent on high quality Numerical Weather Prediction (NWP) models, which rely on steadily improving, sustained sources of data. Satellites have increasingly become the primary source of this data, and the observations of atmospheric temperature and humidity from instruments on satellites have a greater impact on NWP performance than any other observation type[116]. Satellites further provide the only meteorological information available for large parts of the oceans, polar regions and atmosphere, and are critical when it comes to measuring changes in climate variables such as sea level rise globally and in regional detail[117].

As a member of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the Met Office makes contributions of £36.7 million per year to the development and running of satellite programmes which provide the required meteorological data.). In addition, the Met Office spends £1.7 million per year on dedicated satellite applications staff and a further £0.1 million on its satellite data reception facility[118]. The total Met Office expenditure on EO therefore amounts to **£38.5 million** per year.

The use of data from space is highly cost-effective in comparison with alternative forms of acquiring the data, such as through in-situ observing systems or surface-based remote sensing. In particular, while only one third of the Met Office's spend on observations falls on satellite data[119], this data is responsible for about two thirds[120] to the overall quality of Met Office forecasts. The reliable availability of data from space allowed the Met Office to rationalise its terrestrial observation networks when it introduced more satellite data[121]. However, earth- and satellite-based observations constitute complementary inputs into the forecasting process and both observation types are so ingrained in the Met Office's current models that it is not possible to specifically attribute any operational cost savings to the use of meteorological EO data.

Analysis undertaken by London Economics[122] suggests that the annual wider benefits of the Met Office's weather and climate services are in the range £2.2 billion-£3.5 billion[123]. These wider benefits include both avoidance of exceptional costs to government as well as catalytic benefits accruing to the private sector and the general public (see table below).

[116] Several studies have shown that the Met Office's forecasts would be degraded substantially if no satellite data were used: Department of Trade and Industry (2001). *Evaluation of funding for UK civil space activity. Chapter 5: The Met Office report*. Met Office (2005).

[117] UKSA (2014). *EUMETSAT Jason 'Continuity of Service' Satellite Programme.*

[118] Data on the Met Office's expenditure on EO data, including the annual EUMETSAT contribution and expenditure on dedicated staff and the satellite data reception facility, were obtained from McKinsey & Company (2016). 'Earth Observation (EO) Data. How can the Government ensure more efficient and effective use of the increasing volume of EO datasets to improve policy outcomes, reduce costs and stimulate relevant industries?', supporting slides for final report.

[119] Department of Trade and Industry (2001). Evaluation of funding for UK civil space activity. Chapter 5: The Met Office report.

[120] Joo, S., Eyre, J. and Marriott, R. (2013). 'The Impact of Metop and Other Satellite Data within the Met Office Global NWP System Using an Adjoint-Based Sensitivity Method', *American Meteorological Society, vol.* 141 (October), pp. 3331-3342.

[121] Department of Trade and Industry (2001). *Evaluation of funding for UK civil space activity. Chapter 5: The Met Office report*.

[122] London Economics (2015). *Met Office – General Review. Economic Analysis – Final Report.*

[123] The London Economics 2015 study reported net present benefits of £31.8 billion for the period 2015-2024 (in 2015 prices). For the purposes of this study, non-meteorology benefit streams were removed. Numbers have been updated to 2017 prices and undiscounted.

Table 22 Benefits from meteorological observations

Function	Beneficiary	Current
Weather and seasonal forecasts	Public/Private sector	£540.0 million
Extreme weather and hazard warnings	Public/Private sector	£200.2-223.6 million
	Government	£12.7-12.8 million
Industry services (specialist forecasts)	Public/Private sector	£1,381.1 – 2,612.2 million
Climate research	Public/Private sector	£84.2 million
Provision of meteorological data	Public/Private sector	£1.5-1.9 million

The benefits of the Met Office's weather and climate services depicted above result from multiple inputs, including satellite observations, aerial observations, surface-based observations, scientific staff expertise and supercomputer capacity. A conservative estimate of the share of all observations in all inputs feeding into the Met Office's services is considered in the range 30% to 50%[124]. Further, according to a recent study on the observation impacts on the accuracy of 24h forecasts published by the American Meteorological Society, satellite data accounts for 64% of short-range global forecast error reduction out of all observations[125]. While meteorological satellites also make use of other space technologies to derive meteorological data, e.g. through GNSS radio occultation whereby EO sensors sense the effects of the atmosphere on GNSS transmitter signals, those other space technologies only contribute a few percentage points to total weather forecasting accuracy[126].

For this study, it is therefore assumed that 98% of all space-derived observation data is attributable to Earth Observation technologies.

Combining the above data on the benefits of the Met Office's services as well as the input shares found in the literature suggests that the total government cost avoidance enabled by Earth Observations stands at **£3.9 million per year,** while **catalytic benefits** from satellite-based meteorological observations to the UK economy range between **£671.0 and £1,052.4 million per annum.**

EUMETSAT's current satellite programmes are expected to remain in place until 2020 and beyond[127], and hence neither the amount nor quality of the meteorological data collected using Earth Observation technologies is expected to change within the next three years.

However, there is some potential to increase the amount of climate data that is collected through the Global Climate Observing System (GCOS) beyond 2020[128]. For example, the GCOS

[124] Both EUMETSAT (2014) and the Met Office (2014) attribute a weight of 50% each to observations and numerical modelling (HPC and scientists), while the National Oceanic and Atmospheric Administration (NOAA), the American weather agency, estimated the contribution of observations at 30% in 2003 study. For the purposes of this analysis it has been assumed that the benefits of the Met Office's weather and climate services are shared equally between Observations and HPC (in accordance with the more recently published EUMETSAT and Met Office studies). Note that the same share is assumed to hold for weather and climate (again in accordance with the Met Office study).
Eumetsat (2014). *The Case for EPS/Metop Second Generation: Cost Benefit Analysis.*
Turner, S., Truscott, B., Mundy, P. and Barber, A. (2014). *EUMETSAT Polar System-Second Generation. Full Business Case*.
[125] Joo, S., Eyre, J. and Marriott, R. (2013). 'The Impact of Metop and Other Satellite Data within the Met Office Global NWP System Using an Adjoint-Based Sensitivity Method', *American Meteorological Society, vol.* 141 (October), pp. 3331-3342.
[126] London Economics (2017). *The economic impact on the UK of a disruption to GNSS.*
[127] The Meteosat Second Generation programme is estimated to remain as the primary geostationary programme until March 2022 and is valued at depreciated replacement cost. The European Polar Satellite Programme is estimated to remain as the primary polar programme until December 2020 and is valued at value in use.
[128] The Royal Society (2015). Observing the Earth: Expert views on environmental observation for the UK.

Implementation Plan[129] makes reference to new Essential Climate Variables (ECVs) such as greenhouse gas fluxes, oceanic N_20, ocean surface stress and land surface temperature for which satellites have only recently started collecting data.

Table 23 Annual value of EO to UK government in the Meteorology Use Case

Function	Current, realised	2020, potential
Operational cost savings	-	-
Exceptional cost avoidance	£3.9 million	£4.2 million
Catalytic benefits (to wider government, economy, society)	£861.7 million	£962.1 million
Total	**£865.5 million**	**£966.3 million**

Box 10 Wider use of EO for UK government climate policy

EO for greenhouse gas emissions reporting and climate research is covered in the Atmosphere and Meteorology case studies, respectively. While satellite-derived EO are limited in their ability to independently measure cloud properties with sufficient resolution and to penetrate sub-surfaces on land and sea, EO data from space can be integrated with ground-based networks to support climate research, forecasting, and management more broadly. For example, satellite data can be used to:

- Understand trends in regional temperature;
- Measure sea level rise with greater accuracy
- Quantify changes in ice on sea and land;
- Measure the radiation balance of the planet;
- Support emissions trading programmes;
- Support results-based payments for climate-linked ODA funds (e.g. REDD+), and
- Enable changes in climate-related risks and hazards to be detected.

By supporting improved measurement and monitoring in this way, satellites can support the adoption of more effective actions to mitigate climate change. Given the scale of costs that are associated with climate – estimated to be at least 5% of global GDP per year in perpetuity, or at least 20% of global GDP if considering wider impacts, and the required cost of mitigation – at least 1% of global GDP, the value of satellite-derived EO in this context is significant.

Source: The Royal Society (2015). Observing the Earth: Expert views on environmental observation for the UK; Stern, N. (2006). Stern Review: The economics of Climate Change.

3.9 Transport

'Transport' is the movement of goods or people via road, rail, sea, or air. Government activities related to sea transport are considered in the 'maritime' section (3.7). Air transport in the UK is primarily a private sector activity, and it is therefore not prioritised for the present study. Activities related to road and rail transport are in scope. Only government activities that use satellite-derived

[129] Global Climate Observing System (2016). GCOS 2016 Implementation Plan.

EO beyond a nonprofessional's use of Google Maps/Earth and meteorological outputs from the Met Office are considered.

Transport activities in government include a wide range of functions. The annual budget of the Department for Transport (DfT) is £21.7 billion, and activities related to road and rail cost **£17.4 billion**.[130] The vast majority of this expenditure is on construction and maintenance.

Table 24 Government functions in transport

Function	Addressable by EO, current	Addressable by EO 2020	In scope for case study
Rail	×	✓	✓
Road	×	✓	✓
Aviation	×	×	×
Maritime	×	✓	× (see 3.7)

The main government actors in the transport domain are DfT, Network Rail (NR), Highways England, Transport Scotland, Welsh Government, Transport Northern Ireland, and Local Authorities.

Box 11 Case study: Rail and road

Network Rail (NR) owns and manages the UK's rail infrastructure, including tracks, bridges, and major stations. NR accounts for more than half of the total budget in the Department for Transport (DfT). As a Critical National Infrastructure (CNI), the continued operation of the UK's rail network is an absolute priority for NR, which has developed processes to manage risk.

NR is well-informed about satellite-derived Earth Observation (EO) as a potential source of information to mitigate risk relating to geotechnical asset failure and service loss, and has run a trial with EO industry to ascertain whether EO could be used as an input in the risk management by measuring ground movement. Using historical degradations of embankments, NR asked prospective contractors to identify the point at which the EO-based system would recommend intervention. No bidder was able to isolate the failing embankment on pre-collapse images. Either the systems were too sensitive, and therefore identified too many false positives, or not sufficiently sensitive, in which case the failing infrastructure was not identified.

Network Rail does not currently use satellite-derived EO operationally. The organisation, however, actively participates in various projects attempting to develop EO-derived solutions for the railway infrastructure domain under different programmes: SSGP, Innovate UK, and ESA BA.

Network Rail do not anticipate replacing current approaches to risk management for satellite-derived EO as it needs to have complete confidence in the solutions it uses and have absolute certainty in the data being used. However, there is scope for EO to be integrated in novel approaches to risk management One such identified prospective application of satellite EO is the monitoring of land neighbouring the railway corridors. Changes in the use and cover of neighbouring land can affect the absorptive capacity of the land and therefore impact the risk of infrastructure failure. Network Rail do not currently incorporate this information in its models, so adding such data could **enable** an improvement in the models. Given its infancy, the impact of

[130] Department for Transport (2017). *Annual Report and Accounts 2016-17*

the application on the risk of failure cannot be estimated, but assuming the application could avoid 5% of the delays associated with unplanned engineering works, NR could save **£9.0m**.[131] This application is mature across other areas of use, and the potential may already be realised.

Longer term research projects aimed at serving the railways with satellite-based solutions include LiveLand, RailSAT, and EO-SCANS – Earth Observation for the Surveillance of Critical Assets for National Security,[132] all three of which are in progress and expected to complete over the coming year or two. If one or more of these projects proves successful, further savings of 5% of baseline costs associated with unplanned engineering works could be envisaged, worth **£9.0m**.[133]

For road transport, there is currently no documented use of satellite-derived Earth Observation. There is anecdotal evidence that imagery accessed through the activation of the Disaster Charter when the Somerset levels were flooded was used to identify blocked roads and alternative routes for emergency response vehicles, but this use is not operationalised.

As such, the current value of the use of satellite-derived EO in road transport is **negligible**.

However, both the DfT and Highways England (HE) consider the satellite-derived EO a potential source of value in future, but in order to realise this value, temporal resolution needs to improve, and complicated pattern recognition algorithms need to be developed.

Concrete challenges that satellite-derived EO may play a role in solving are presented below:

A national asset database with regular updates that would allow the authorities to keep detailed information on the location and status of road furniture, bridges, streetlights, and foliage would enable more efficient use and management of the network. In order to ensure smooth operation of the road network, it is important that all relevant authorities are aware of properties of the network. Trees next to the road may grow in a way that impedes certain types of vehicles, which necessitates trimming.

If a member of the public advises that a piece of street furniture is damaged (e.g. a road sign), they tend to make such reports with reference to local landmarks that are not necessarily known to the operator receiving the call.

Having a centralised database of information related to road width and other properties of the road (e.g. the axle-load it can carry), could improve the efficiency of re-routing in relation to roadworks. Such information could also be of interest to manufacturers of satellite navigation equipment and autonomous cars in the future.

In addition, the monitoring of the health of the bridges on the network is a costly activity, where local authorities in Great Britain annually spend an estimated £44.4m.[134] Development of a method that could separate weaker and stronger bridges, and allow more targeted ground monitoring by a mere 10%, would enable annual council-level savings of **£4.4m**. Beyond these

[131] Network Rail (2017). *Payments for disruption on the railway*.

[132] More information at http://liveland-service.com/; https://business.esa.int/projects/railsat; and https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/637775/Emerging_and_Enabling_Technologies_Round_1_-_Stream_2_-_24_months_-_Competition_Results.pdf, respectively.

[133] Network Rail (2017). *Payments for disruption on the railway*.

[134] Based on the number of bridges and costs of monitoring in one council (approx. £600 per bridge per year) and scaled up using the number of bridges in Great Britain from RAC Foundation (2018). *"Number of substandard bridges rises"*. Available at: https://www.racfoundation.org/media-centre/number-of-substandard-bridges-rises [accessed 7 June 2018]

'simple' operational costs savings, the earlier identification of failing bridges and consequent opportunity for more timely intervention is likely to result in an overall reduction in bridge maintenance costs. According to the RAC Foundation,[135] Councils in Great Britain have a maintenance backlog of almost £2,978m in 2018 up from £2,390m the year before[136]. If timely intervention based on EO-derived information could halt this development by 10%, exceptional costs of **£60m** could be avoided. Further impacts arising from the reduced or avoided closure of bridges (that forces drivers to take longer routes and use more time and fuel) are easy to imagine.

Traffic monitoring is currently based on manual counts. Annual figures are based on 8,000 annual point counts, and the gaps are then estimated. Additionally, Automatic Traffic Counters (ATCs) collect constant traffic information on 200 key sites. Traffic counts in the UK is a costly activity with the DfT alone spending £4m per year and additional costs at the Devolved and Local Authority levels. Traffic information is also available through data purchase from Waze, the navigation app that takes traffic into account in computing the best route.

Traffic monitoring is important, as the information is used to estimate the UK's Greenhouse Gas (GHG) emissions bottom-up in the National Atmospheric Emissions Inventory. The UK spends £1.8m per annum on the maintenance of the National Atmospheric Emissions Inventory,[137] and as road transport accounts for 24% of total emissions,[138] it is reasonable to assume that a 25% improvement in the traffic information feeding the inventory could generate catalytic benefits of at least **£100k**.

Satellite-derived EO is not likely to be able to replace existing methods entirely as certain roads will always require costly infrastructure (ATCs), and others will need a full day's survey. Nevertheless, it is reasonable to assume that considerable savings could be realised by incorporating EO in the process, and only count manually when really needed. Assuming the DfT's expenditure on traffic is a reasonable estimate of what could be saved, the potential 2020 saving is **£4m**.

Activities undertaken using traffic cameras (similar to ATCs) could theoretically be replaced satellite-derived EO sources. This is especially true for rural areas, where the cameras are dispersed, and coverage could be improved. In case of traffic incidents, cameras are used to gather information, so areas without coverage could benefit from access to images or video from satellite. The annual operating cost of traffic cameras is £150,000, so if an EO-based solution could reduce the need for cameras, local authorities would likely be interested. The replacement of cameras would, however, require better temporal resolution than is expected by 2020.

Table 25 Benefits from satellite EO in transport applications in scope

Function	Beneficiary	Value current
Rail	Public sector	Negligible
Road	Public sector	Negligible

[135] RAC Foundation (2018). *"Number of substandard bridges rises"*. Available at: https://www.racfoundation.org/media-centre/number-of-substandard-bridges-rises [accessed 7 June 2018]
[136] RAC Foundation (2017). *"More than 3,000 GB road bridges are substandard"*. Available at: https://www.racfoundation.org/media-centre/spanning-the-gap-road-bridge-maintenance-in-britain [accessed 7 June 2018]
[137] Delta eSourcing (2016). *The Department for Business, Energy and Industrial Strategy (BEIS): Contract to deliver the UK's National Atmospheric Emissions Inventory*. Available at: https://www.delta-esourcing.com/respond/2BJD827574 [accessed 4/4/2018]
[138] Department for Business, Energy & Industrial Strategy (2018) *Final UK greenhouse gas emissions national statistics: 1990-2016*. Available at: https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2016 [accessed 4/4/2018]

Satellite-derived EO is considered an interesting prospect for the transport activities covered here, with potential to add value. However, historical promises made on behalf of EO that have not been realised, has made the operators in government sceptical. The critical nature of the transport network means that EO-based methods must establish a long heritage before they can be considered as credible alternatives and the ability of EO to continue existing and long data series in a consistent and seamless way is important for uptake in transport.

Between now and 2020, specific applications of interest to both rail and road transport authorities could be developed, and value could be created along the lines discussed in the box.

Table 26 Annual value of EO to UK government in the Transport Use Case

Function	Current, realised	2020, potential
Operational cost savings	-	£8.4 million
Exceptional cost avoidance	-	£78.0 million
Catalytic benefits (to wider government, economy, society)	-	£0.1 million
Total	**-**	**£86.5million**

3.10 Summary of case studies

This section has reported on nine case studies across government functions, with aggregate annual value estimates reported in Table 27 below for the two scenarios of interest: current; and 2020, potential value.

The majority of value is found in meteorology, where a specialised government trading fund, with more than fifty years' experience using satellite-derived Earth Observation, delivers the value for government, as well as the private sector and general public.

Table 27 Annual value of EO to UK government by Use Case: total estimate (including catalytic benefits)

Function	Current	2020, potential
Agriculture	£45.1 million	£75.4 million
Atmosphere	-	£4.3 million
Built environment	-	£8.3 million
Coastal	-	£6.9 million
Flooding	£17.2 million	£24.3 million
Forestry	£3.1 million	£60.7 million
Maritime	£12.1 million	£15.6 million
Meteorology	£865.5 million	£966.3 million
Transport	-	£86.5 million
Total	**£943.0 million**	**£1,248.3 million**
Total excluding Meteorology	***£77.5 million***	***£282.0 million***

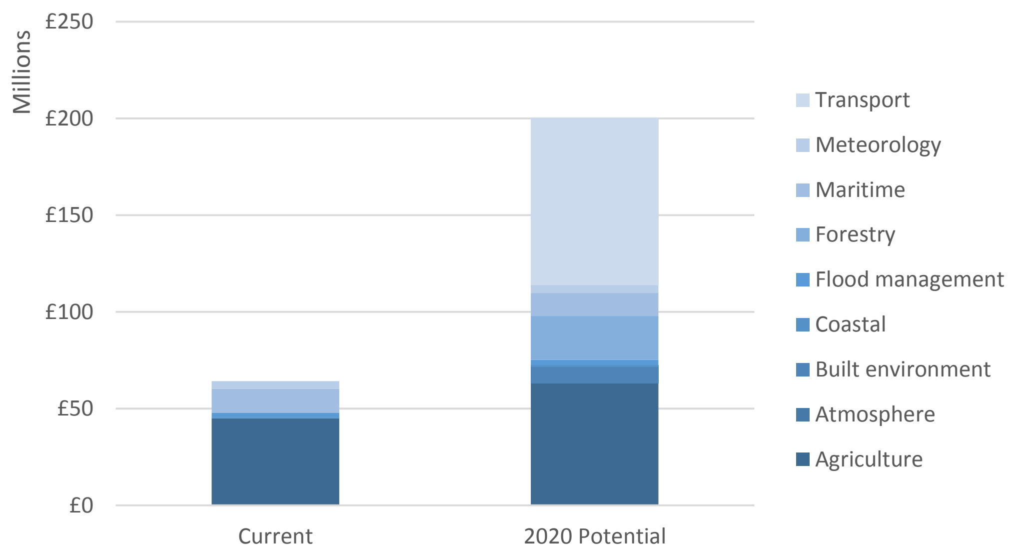
The major driver of value in meteorology is catalytic benefits to the private sectors and general public rather than the government itself. Considering instead only the operational cost savings and exceptional costs avoided by government (i.e. a stricter definition of value of EO to the UK government), the picture changes.

Table 28 Annual value of EO to UK government: operational cost savings and exceptional cost avoidance only

Function	Current	2020, potential
Agriculture	£45.1 million	£63.1 million
Atmosphere	-	-
Built environment	-	£8.3 million
Coastal	-	£1.0 million
Flooding	£2.8 million	£2.8 million
Forestry	£0.3 million	£22.7 million
Maritime	£12.1 million	£11.8 million
Meteorology	£3.9 million	£4.2 million
Transport	-	£86.4 million
Total	**£64.2 million**	**£200.9 million**
Total excluding Meteorology	***£60.9 million***	***£196.1 million***

Agriculture currently generates the greatest value for UK government at more than 70% of annual estimates and remains a key contributor in 2020. The potential value in 2020 is substantially greater than the current for forestry and transport. This potential is contingent on the right applications and solutions being developed between now and 2020.

Figure 2 Annual value of EO to UK government: operational cost savings and exceptional cost avoidance only



Source: London Economics analysis

4 Value of service provision by UK industry

As part of this study's data collection, UK companies in the Earth Observation industry were invited to attend a half-day workshop, and many accepted the invitation.

The workshop covered industry's impression of the value of satellite-derived EO to UK government, including current and future supply and capabilities within industry. This objective was to gather industry input, which could be used to: i) validate findings from government and expert stakeholders, and ii) identify industry views on the capabilities of satellite-derived EO today and its expected development by 2020.

4.1 Current provision to UK government

It has been found that industry supplies optical and SAR data in the following areas: Forestry, Maritime, Flooding, and Agriculture; and supplies change detection services and tools to analyse and visualise EO data across a number of areas.

The UK's membership of the International Disaster Charter is operationally managed by industry, which responds if the charter is activated.

Putting these individual examples aside, workshop attendees perceived there to be a highly variable, but generally low level of EO use across government. Specific champions in government were recognised, such as Defra – which, through its *Roadmap for the Use of Earth Observation* and leadership of the *EO Centre of Excellence* – was acknowledged as having a clear commitment to EO. However, industry has found it difficult to engage with other areas of government.

UK industry has also demonstrated these capabilities to government via a number of grant-funded programmes (e.g. SSGP, Innovate UK, ESA BA). However, none of these projects has yet translated into a long-term procurement for a product or service from industry on a commercial basis.

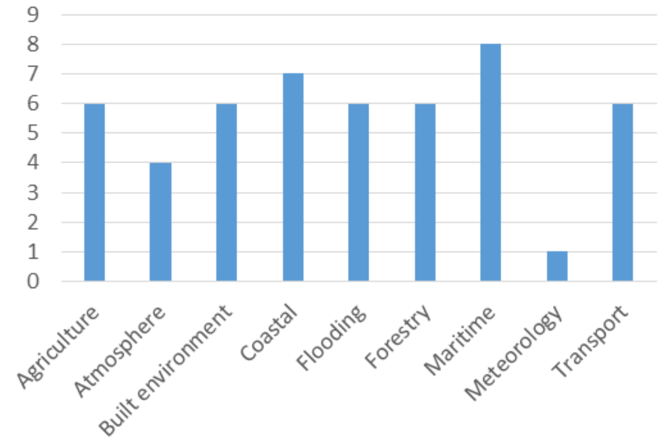
One area of commercial provision has been in the acquisition of high-resolution data in specific use cases. The RPA is a notable example. However, this data has largely been acquired from the US (Digital Globe) and France (SPOT).

4.2 Potential future supply

UK industry was also able to provide an account of what they might be able to supply to government in the future. Annex 2 summarises the services and solutions industry identified as current and future possibilities within each of the use cases.

Industry representatives report that a solution exists for all use cases. For most of the use cases, approximately half a dozen different solutions are available. For Meteorology, however, only one new solution has been proposed. For information on the specific solutions proposed, please see Annex 2.

Figure 3 Number of example solutions from UK industry by use case



4.3 Value to industry of supply to UK government

The current value of **commercial** supply (i.e. excluding grant-funded projects) to UK government from industry organisations contributing to this study is in the order of **£10m** per annum. The UK industry have ambitions to quadruple this figure in the near future, with solutions and offering available to take the total value to UK industry of supply of EO data and solutions to UK government to **£40m** per annum.

Considering instead the supply of projects for UK government applications funded by grants from UK government, the current value received by workshop attendees is less than **£3m** per annum. However, industry attendees have identified ambitions to double funding receipts to **£6m**.

4.4 Exports of satellite-derived EO solutions

UK companies are very successful at competing internationally, exporting a diverse range of EO capabilities across the full value chain of EO. The supply of EO solutions to foreign governments from UK operations, based on the sample of data returns, is currently in the order of **£22m** per annum, with ambitions to grow to **£250m**.

Were the industry to realise these ambitious export targets, then the industry-wide export targets set in the Space IGS[139] (£25bn by 2030) would be a step closer.

It should be noted that some of these EO-focused solutions are also being delivered via the UK Space Agency's International Partnerships Programme (IPP). The IPP uses the UK space sector's capacity to deliver satellite-based services for public sectors in the developing world. EO solutions account for 76% of all projects in the first call, all of which are being delivered by UK industry or academia. The scale of this funding for a domestic-focused programme could greatly enhance national EO capability and uptake.

5 Barriers to adoption

As part of the industry workshop, attendees from industry were asked to identify the main challenges to delivering EO capabilities to UK government. The following represents a synthesis of their views:

- **Maturity of existing monitoring infrastructure:** Existing UK methods for collecting non-satellite data are good and fit-for-purpose. It was acknowledged that there are a number of areas that are already adequately serviced by terrestrial/aerial sources where satellite-based EO would not add value.
- **UK cloud cover and coastal turbidity:** Optical-based EO satellites are unable to penetrate clouds or turbid (murky) sea. This represents a particular problem for the UK, which is characterised by abundant cloudiness, particularly around Scotland, and turbidity immediately around the UK's coast. This restricts the value of optical-based satellite for maritime, coastal, and land monitoring applications. Nevertheless, SAR has the capacity to mitigate some of these problems.
- **Interdependency with other data sources:** Much of the value of satellite-based EO lies in its capacity to augment data from other sources, however this potentially is not fully

[139] Space IGS (2013) *Space Innovation and Growth Strategy 2014-2030, Space Growth Action Plan.*

realised at present. In the atmosphere use cases, satellite-data could be used to augment ground-based data to support more accurate monitoring and forecasting activities.

- **Government capacity:** The government faces a number of constraints that limit their use of EO. At a fundamental level, many areas of government lack the expertise to understand the value and application of EO. Where this is understood, funding pressures make it difficult for officials to procure solutions and access paid-for data from industry and a combination of these budgetary constraints and skills shortages makes it difficult for departments or agencies to extract value from EO data by applying advanced machine learning or other analytical techniques. These capabilities exist within UK industry, so represent an area where UK industry can enhance the use of EO applications and services in government
- **Fragmented procurement:** At present, there is no single co-ordinating body for the procurement of EO data or solutions in UK government. This means that industry must approach, build relationships with, and demonstrate feasibility and value to multiple officials in government for each application. This raises the cost of business development and therefore the attractiveness of supplying to UK government on a commercial basis. This also represents a potential inefficiency on the government side, where there may be duplicate procurements of the same data. The proposal for a UK Government Earth Observation Service concept (UK GEOS) was identified as a potential solution to this. 'Earth Observation Australia' – Australia's cross-sector coordinating body for EO data was cited as a potential model for a UK GEOS concept.
- **Government procurement methods**: Stakeholders on both side of procurement confirm difficulties ascertaining the requirements of government. There is an apparent tendency that government specifies requirements based on currently achieved performance (i.e. that achieved by the non-EO solution) rather than the minimum requirements for the successful completion of the application.
- **Understanding of value proposition:** Industry communicated that many departments and agencies appear to lack an understanding of the value that EO can deliver at the highest (decision-making) levels. There are some champions in government, such as Defra, UKSA and the Geospatial Commission, but to date this has not supported the progression of services or products from a grant-funded pilot (e.g. SSGP) to full operational basis on commercial terms. This gap between the EO capabilities offered by industry and government's understanding of the value this offers means that the potential value of EO is likely higher than the estimate provided in this report.
- **Government reliance on Sentinel data:** The 'free at the point of use' concept which underpins the Copernicus programme has encouraged wide use of EO data, but it has undermined the value proposition of commercial data providers. This was a view held by many government stakeholders that cited significant budget pressures. Nevertheless, the value of commercial data sources should be acknowledged – many offer significant improvements to temporal and spatial resolution that cannot be matched by Sentinel data. For this reason and in some cases, the full value from EO can be realised in a model where free-to-access data is used to provide high-level risk detection, and commercial sources of data are used for detailed assessment. For application innovation within industry, it should be noted that Sentinel data represents an enabler rather than a barrier for some providers.
- **Regulatory standards:** There are a number of areas where satellite-derived EO for atmosphere applications is hampered by the technical reporting and monitoring standards that are mandated by legislation. For example, European regulatory standards do not permit the use of satellite-derived EO for monitoring and reporting UK compliance against the European Air Quality Directives.

Additionally, the following barrier was identified through consultations with government:

- **Need for a strategic product:** Resource and skill constraints in government makes it difficult for officials to acquire, process, interpret and analyse data for bespoke needs, at a frequency that makes it a viable input into operational processes. This constraint limits the usability of EO and raises the cost of implementing individual applications of EO. Strategic products that allow users to bypass these pre-application processes could drastically lower the resource cost associated with using EO data and support wider use. Defra's Centre of Excellence's investment in 'EO Alpha' represents one project within Defra's wider Data Transformation Programme[140] that attempts to do this, using the capabilities offered by UK industry. The UK government's Industrial Strategy Challenge Fund (ISCF) may also provide an opportunity for industry to contribute to a wider strategic solution.

6 Conclusion

This research has quantified – wherever possible – the value of satellite-derived Earth Observation to UK government across nine case studies. **The findings in this report therefore relate to the specific functions in the scope of the use cases studied**, with potential further value in the same areas or other areas of government activity not considered. The research has focused on the currently realised value of satellite-derived EO, and the potential for 2020 – assuming the required developments in terms of EO applications occur. This study quantifies three definitions of value:

- **Operational cost savings** where the use of EO by government replaces a more expensive method;
- **Exceptional cost avoidance** where the use of EO allows the government to take measures to avoid costs, and where these go beyond what is possible with other methods; and
- **Catalytic benefits** where the government's use of EO allows non-government actors to derive utility or save money.

This study has also identified other sources of value that cannot be monetised. This includes the value associated with better policy decisions and regulations that are enabled by EO.

6.1 Total value per annum

The total value of satellite-derived Earth Observation for government applications has been estimated at **£943 million,** and **£1,248 million** for current, and 2020 potential, respectively.

This represents significant value to the UK government and wider society.

At more than 90% of this value today, **Meteorology** accounts for the vast majority. This is no surprise given the Met Office's internationally leading position among national weather services, and the more than 50 years of experience accumulated at this particular government trading fund. For these reasons, this estimate reflects both the maturity of EO use in the area and also the value that accrues to a number of diverse areas that rely on meteorological EO data to inform mitigation efforts and

[140] For more details, please see: https://media.sa.catapult.org.uk/wp-content/uploads/2017/03/11101346/Use-Cases-from-the-Defra-JNCC.pdf

timeliness of intervention. There are four other areas in which the government currently uses EO and these are: Agriculture, Flooding, Maritime, and to a less extent, Forestry.

Table 29 Value of EO to UK government by Use Case

Function	Current	2020, potential
Agriculture	£45.1 million	£75.4 million
Atmosphere	-	£4.3 million
Built environment	-	£8.3 million
Coastal	-	£6.9 million
Flooding	£17.2 million	£24.3 million
Forestry	£3.1 million	£60.7 million
Maritime	£12.1 million	£15.6 million
Meteorology	£865.5 million	£966.3 million
Transport	-	£86.5 million
Total	**£943.0 million**	**£1,248.3 million**
Total excluding Meteorology	***£77.5 million***	***£282.0 million***

Considering the potential in 2020, just over half of the potential growth is within **Meteorology**, but assuming the necessary developments in **Forestry** materialise, these activities could generate value almost 20 times what is currently realised. Similarly, the potential value in **Transport** is considerable, and worth pursuing.

It should be noted that these estimates of the (current and potential) value of EO to UK government capture monetisable savings that accrue to UK government and wider society. Other non-monetisable source of value are not captured in these figures. For example, the value associated with EO supporting better policy making and regulation, and enhancing operational productivity, are likely to be significant, but are not quantified in this study.

In the context of significant pressure on public resources, higher demand, and increasing public scrutiny, EO offers a clear value proposition that is not fully captured in these estimates of value. More specifically, EO's capability to support the detection of change over large areas, often more quickly and more cheaply than other methods, means that EO can be used: i) with machine learning techniques to support continuous risk monitoring and enhance the deployment of other non-EO methods for more detailed observations of identified risks, and ii) to provide publicly-available information that can support voluntary interventions by non-government actors.

In other words, EO can enhance public service delivery even as potential risks mount and departmental resources shrink.

6.2 Internal government value (only) per annum

The previous subsection considered the total value estimated, including catalytic benefits that, *by definition*, benefit non-government actors. In other words, these benefits are generated by the government's use of satellite-derived Earth Observation, but enjoyed by others.

Removing the catalytic benefits from the analysis, presents a different picture, and answers the very core of the research question: what is the value **to government** of its use of satellite-derived Earth Observation. Table 30 thus presents the findings excluding catalytic benefits.

The most striking result is that Meteorology only accounts for a small proportion of the value under this definition of value. This is partly explained by a conservative estimate of meteorological impact as activities related to forecasting and preventing storm damage are presented as 'catalytic' irrespective of the actual owner of the assets, but mostly a reflection of the 'public good' nature of meteorology, and the fact that the whole society benefits from weather forecasts.

Agriculture is the dominant use case with more than half of value generated, followed by Maritime as the second-most valuable use case. Both have EU agencies and EU regulation at their core, and the value (proposition) could look very different on 1st January 2021, after the UK has left the EU and the transition period has elapsed.

Table 30 Value of EO to UK government per annum: operational cost savings and exceptional cost avoidance only

Function	Current	2020, potential
Agriculture	£45.1 million	£63.1 million
Atmosphere	-	-
Built environment	-	£8.3 million
Coastal	-	£1.0 million
Flooding	£2.8 million	£2.8 million
Forestry	£0.3 million	£22.7 million
Maritime†	£12.1 million	£11.8 million
Meteorology	£3.9 million	£4.2 million
Transport	-	£86.4 million
Total	**£64.2 million**	**£200.3 million**
Total excluding Meteorology	***£60.3 million***	***£196.1 million***

Note: †: The reduction in value is due to a global trend of reduction of oil spills and consequent reduction in damage prevention.

Forestry and transport are foreseen to offer significant potential value by 2020, from a low current baseline.

On the evidence of this research, the overall potential for EO use by 2020 represents a trebling in direct value (i.e. operational cost savings and exceptional cost avoidance) for UK government to £200 million. Additional direct value to be gained in 2020 include: Agriculture (£18 million), Built Environment (£8 million), Coastal (£1 million), Forestry (£22 million), and Transport (£86 million).

In light of these findings it is worth reiterating that the need to maintain service provision (and minimise risk) in the face of pressure on government resources, higher demand, and desire for more transparency – suggest a stronger value proposition for EO in the future. In this world, free-to-access data will likely have a role in supporting continuous risk monitoring (and providing information which non-government actors can use), and higher specification EO products from the private sector could support more detailed observations of identified risks.

6.3 UK industry

The UK government's use of EO is estimated to support approximately **£10m** in commercial revenue and **£3m** in grant-funded projects per annum for UK industry. This is consistent with industry views that the use of EO across UK government today is highly variable and generally low. This is based on a sample of responses from industry contributors to the study. The actual figure is likely to be larger.

The results from this study indicate that the potential for EO both today and by 2020 appears to be greater. Indeed, some of the more sophisticated government uses of EO that have been identified for the future imply high-specification EO capabilities that can be provided commercially. This should correspond to higher demand for EO capabilities from UK industry in the future.

However, if this value and corresponding demand for UK industry capabilities is to be realised, the UK government must address a number of barriers to adoption. These largely concern internal constraints to both procure and use EO data and applications (i.e. access to budgets, skills, coordinated procurement strategy, maintenance of EO capabilities post-Brexit).

6.4 Value of EO in the context of Brexit

The UK's impending exit from the EU (Brexit) presents two uncertainties in this analysis:

- The first concerns potential changes to the UK's **access to and capability to exploit Sentinel data**;
- The second concerns value that is derived solely from **EO use in areas that are driven by compliance with EU legislation**.

The implication of these two uncertainties by 2020 and beyond are detailed below.

6.4.1 UK's access to and capability to exploit EO data

The relatively short timeframe for this analysis (now to 2020) means that all identified areas of current and potential use of EO in government, and their associated value, assume continued access to Copernicus (including Sentinel data) on the same terms as now. This access could change following Brexit, on 29th March 2019, and completion of transition period (31st December 2020). This creates an uncertainty about the UK's access to EU-funded programmes after this point.

For example, a substantial proportion of Sentinel data is freely accessible to non-EU countries. However, some Sentinel satellites are programmed to prioritise data acquisition over certain areas[141]. This is called 'tasking'. The UK's discontinued participation in the programme could therefore imply a loss of data over the UK, particularly for Sentinel's 1, 2, and 3, which are thought to provide the most benefits to the UK government. For example, Sentinel-1 is the most constrained satellite and is particularly valuable to the UK because of its SAR capability to penetrate cloud cover. Similarly, a combination of non-participation in the programme and a failure to invest in domestic data processing capability could reduce the UK's capacity to process and exploit some of the most high-specification outputs from Copernicus. This is because this capability currently exists offshore in Europe and access to it could be lost post-Brexit.

Given the reliance on Sentinel data identified in this study, the loss of data over the UK and in the UK's processing capability could compromise the value of EO to government in most areas.

6.4.2 Value of EO use in areas that are driven by compliance with EU legislation

Several areas of current EO use that have been identified in this study are driven solely by the UK government's compliance with EU legislation. For example, the use of EO for CAP-related monitoring and data quality assurance generates all identifiable operational costs and exceptional cost savings in the agriculture use case. The extent to which EO continues to generate value in these areas therefore depends on the extent to which these areas are still applicable to the UK post-Brexit.

[141] For details of Sentinel acquisition plans, please see: https://sentinel.esa.int/web/sentinel/missions/sentinel-2/acquisition-plans

6.5 Recommendations and next steps

Based on the findings of this report, the following recommendations are suggested for consideration:

- Increased co-ordination across government entities to consolidate requirements and points of engagement with industry;
- Greater utilisation and wider co-ordination of the EO practitioner community across government, research and academia, building on the UK GEOS concept;
- Further provision of EO learning and development by EO experts to government, to increase the understanding of EO capabilities and EO applications, as well as future technology developments;
- Increased interaction and engagement between government entities and industry. This could involve greater communication of requirements by government, and technology developments (in terms of data and applications) by industry. Ongoing engagement through the 'R&D to operations' phase would enable government to help steer technology developments to meet future requirements. This could help accelerate the adoption and maturity of applications, building on the work of current initiatives such as SSGP and the Defra EO Centre of Excellence;
- Greater use of existing tools including downstream R&D programmes to enable R&D efforts to be directed to government requirements;
- Consideration for strategic infrastructure to facilitate access to and use of exploitable data for users and application developers; this could also enable greater integration with other complementary geospatial datasets; and
- Repeat assessment of EO use and value to government and industry in three years' time, given future technological developments, the anticipated role of the Geospatial Commission, and resolution of post-Brexit uncertainties.

Index of Tables, Figures and Boxes

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ANNEXES

Annex 1 Glossary

AI	Artificial Intelligence
AIS	Automatic Identification System
AME	Annually Managed Expenditure
APHA	Animal and Plant Health Agency
ATC	Automatic Traffic Counter
BEIS	Department for Business, Energy & Industrial Strategy
BPS	Basic Payment Scheme
CAP	Common Agricultural Policy
CEFAS	Centre for Environment Fisheries and Aquaculture Science
CEH	Centre for Ecology and Hydrology
CH4	Methane
CLC	Correlated Land Change
CNES	Centre National d'Études Spatiales
CNI	Critical National Infrastructure
CroME	Crop Map of England
DCLG	Department for Communities and Local Government
Defra	Department for Environment, Food, and Rural Affairs
DEL	Delegated Expenditure Limit
DEM	Digital Elevation Model
DfT	Department for Transport
EA	Environment Agency
EBV	Essential Biodiversity Variables
EC	European Commission
EEZ	Exclusive Economic Zone
EMSA	European Maritime Safety Agency
EO	Earth Observation
ESA	European Space Agency
ESA BA	European Space Agency Business Applications
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCERM	Flood and coastal erosion risk management
FCGB	Forestry Commission GB
FFC	Flood Forecasting Centre

FGS	Flood Guidance Statements
FLEX	Fluorescence Explorer
FTE	Full-time equivalent
GB	Great Britain
GDP	Gross Domestic Product
GEOS	Government Earth Observation Service
GHG	Greenhouse Gas
GMES	Global Monitoring for Environment and Security
GVA	Gross Value-Added
HABs	Harmful Algal Blooms
HMT	Her Majesty's Treasury
IAP	Integrated Applications Programme
IGS	Innovation and Growth Strategy
InSAR	Interferometric Synthetic-Aperture Radar
IPP	International Partnerships Programme
ISCF	Industrial Strategy Challenge Fund
JNCC	Joint Nature Conservation Committee
LAQM	Local Air Quality Management
LCM	Land Cover Map
LLFA	Lead Local Flood Authorities
LIDAR	Light Detection and Ranging
LPIS	Land Parcel Identification System
LULUCF	Land Use, Land-Use Change and Forestry
MACC II	Monitoring Atmospheric Composition and Climate Interim Implementation
MCA	Maritime and Coastguard Agency
MHCLG	Ministry for Housing Communities and Local Government
MMO	Marine Management Organisation
MOD	Ministry of Defence
NAEI	National Atmospheric Emissions Inventory
NDC	Nationally Determined Contribution
NDVI	Normalised Difference Vegetation Index
NHS	National Health Service
NIS	National Inventory System
NR	Network Rail
NWP	Numerical Weather Prediction

OS	Ordnance Survey
PE	Potential Evaporation
REDD	Reducing Emissions from Deforestation and Degradation
RPA	Rural Payments Agency
SAR	Synthetic Aperture Radar
SSGP	Space for Smarter Government Programme
SMI	Soil Moisture Index
UAV	Unmanned Aerial Vehicle
UK	United Kingdom of Great Britain and Northern Ireland
UK HO	UK Hydrographic Office
UKSA	UK Space Agency
UN	United Nations
UNECE	United Nations Economic Commission for Europe
US	United States of America
VHR	Very High Resolution

Annex 2 Examples of UK industry capabilities

As part of the data collection exercise underlying this report, a sample group from UK industry were asked to detail specific capabilities across the use cases considered. This annex provides a long list of capabilities – should any government reader see something of interest, LE can supply contact details.

A2.1 Agriculture

- Remote land motion monitoring over rural areas
- Crop health + type
- Livestock + wild animal monitoring
- Cartographic + active extraction
- Harvest prediction
- Mangrove, and tree plantation mapping (demonstrated for other governments), are applicable for agriculture monitoring in UK
- Provision of field boundary mapping and bio-physical parameters using EO data

A2.2 Atmosphere

- Monitoring health of peatland, GHG indicator
- Micro Carb
- Service providing air quality modelling data and information, with satellite vehicle counts as the primary input
- Using the Tropomi sensor (from the Sentinel-5 Precursor) we can deliver air quality monitoring services (initially for CH_4)

A2.3 Built environment

- Urban monitor (Change detection, Building rates, feature extraction)
- Change in land motion & calibration with other datasets
- EU programme: Greensurge
- 3D mapping + change over time
- Building type + construction characterisation
- Ground stability (InSAR), basemapping
- Monitoring of land-use change and provision of change detection information

A2.4 Coastal

- Coastal land motion
- Land creep change
- Coastal Erosion, Coastal mapping
- Satellite-derived bathymetry
- 3D mapping + change
- Port security + operations

- Change detection - twice daily
- Coastal stability (InSAR)
- Vector Shoreline product for coastal monitoring, alongside the Satellite Derived Bathymetry and terrain models
- Surface Movement Monitoring using TerraSAR and Sentinel 1 (and PAZ from mid 2018) – Pilot project already in progress with the Environment Agency

A2.5 Flooding

- Dynamic terrain model to support flood risk modelling
- Water table motion (National Land Motion Service)
- 3D mapping
- Building vulnerability
- Rapid mapping and low latency via UKSAR ground station
- Rapid flood mapping
- Flood planning, defence and response activities, as well as live flood mapping

A2.6 Forestry

- Tree monitoring near assets, e.g. power lines and utility assets
- Land motion over forest areas
- Deforestation monitoring. Land cover mapping
- Tree damage via change detection
- Mangrove, and tree plantation mapping (demonstrated for other governments), are applicable for agriculture monitoring in UK
- Change Detection for forestry monitoring, provision of the Starling de-forestation information service and biomass calculations

A2.7 Maritime

- Marine litter
- Oil Spill monitoring
- Algae monitoring
- Soil moisture
- Ocean salinity, sea surface salinity
- Ocean colour
- EU programme: OPERAS, around ecosystem ferries
- Oil spills, shipping monitoring, smuggling, export tracking
- Vessel detection/AIS correlation and behaviour modelling / alerting
- Offshore pollution benchmarking and monitoring
- Satellite-derived Bathymetry
- Oil spill monitoring service
- Vessel Detection/Illegal Fishing (IUU) service

A2.8 Meteorology

- Impact of sea surface salinity on climate

A2.9 Transport

- Governmental Land motion affecting road and rail
- Asset maintenance assessments of all kinds
- Traffic monitoring city-wide, globally
- Embankment/ cutting monitoring
- Structure / ground stability (InSAR), geohazards, basemapping
- Provision of road and rail condition monitoring/change detection services, vegetation assessment services and hosting services

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